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LIME-STABILIZED NATIVE SOIL AS A BASE COURSE FOR LIGHT AIRCRAFT--ETC(U)

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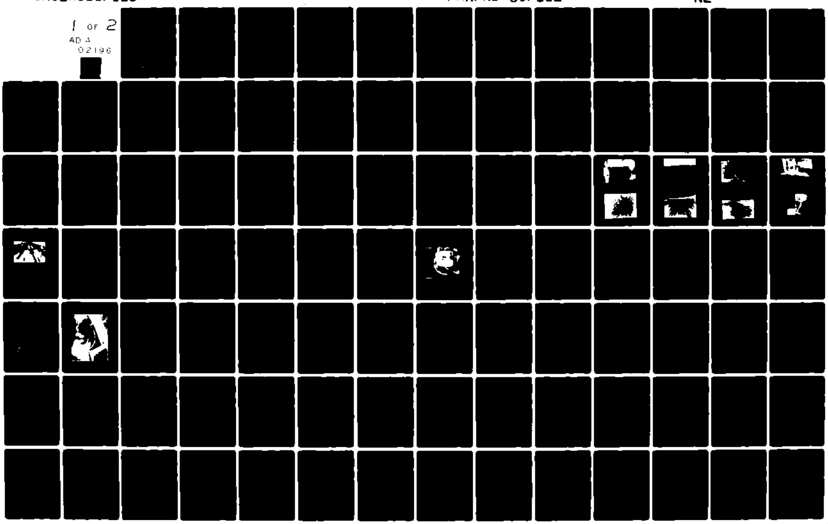

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Lime-Stabilized Native Soil As A Base Course For Light Aircraft Pavement

R.B. BROWNIE

April 1981

Final Report

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16. Abstract

Present Federal Aviation Administration (FAA) policy does not recommend the use of lime-stabilized soil as base course for airport pavements. The potential savings in cost and materials by using this type of construction for light-duty airport pavements (aircraft gross weights less than 30,000 lbs) led to the use of lime-stabilized native soil in place of other base course materials at three airports in the Southwestern United States. Those airports are located at Chino, CA; Big Bear Lake, CA; and Payson, AZ. The compositions of those base courses were determined by laboratory analyses of core borings and soil samples. Visual condition surveys were performed, and surface deflections under load were measured. Climatological data and aircraft traffic histories were obtained. All of those factors and the performance of the pavements were analyzed, and a suggested specification was prepared for constructing lime-stabilized base courses.

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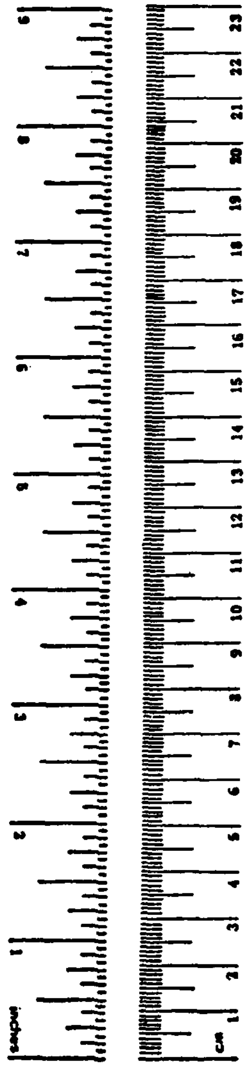
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

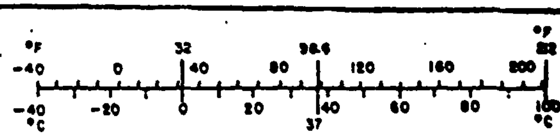
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10.286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SECTION I

INTRODUCTION

Objective

Present Federal Aviation Administration (FAA) policy does not recommend the use of lime-stabilized soil as base course for airport pavements. The possibility of potential savings in cost and materials by using this type of construction for light duty airport pavement (aircraft gross weights less than 30,000 lbs) led to the use of lime-stabilized native soil in place of other base course materials at three airports in the Southwestern United States. These airports are located at Chino, CA; Big Bear Lake, CA; and Payson, AZ. The purpose of the investigation in this report is to evaluate the performance of the pavements constructed using this technique and to develop criteria for preparation of FAA standards. This study was initiated by the FAA through Interagency Agreement DOT-FA78-WAI-834. The Technical Representative for the FAA was Mr. Fred Horn.

Background

Soil stabilization with lime has been used for many years. Beneficial changes in many engineering properties can be achieved through lime treatment. Lime treatment has been used primarily to treat fine grained soils and the fine grained portion of granular materials.

The addition of lime to soil initiates several reactions. A cation exchange and flocculation-agglomeration occurs rapidly and causes changes in plasticity and workability. If soil silica and alumina are present a further soil-lime pozzolanic reaction can form cementitious materials which leads to increased strength. The first changes which occur can be characterized as "modification" and the second as "stabilization."[1]

The position of lime-treated soil layers in the pavement structure is generally determined by the quality of the lime-treated layers and by pavement design parameters. While lime-treated soils have been widely used for subgrade and subbase layers, base course layers have been less frequently constructed of lime-treated soil, particularly in airport pavements. A previous investigation has recommended against using lime-treated soil for base course layers in light aircraft pavements.[2] Thus construction of pavements with lime-treated soil at Chino, Big Bear, and Payson provides a unique opportunity to evaluate the performance of this material in actual pavement sections.

Approach

To evaluate the pavements constructed using lime-treated native soil as a base course layer at Chino, Big Bear, and Payson, field and laboratory testing was performed. The main thrust of the effort was to determine the performance of the pavements exposed to aircraft traffic and environmental effects. The types of tests performed and data collected are summarized in Table 1.

SECTION II

FIELD TESTING

Field testing and data collection consisted of gathering information on the construction of the lime-stabilized pavements, aircraft traffic data, climatological data, and a visual survey of the condition of the pavements. Additional physical testing at each airport consisted of making surface deflection measurements, coring the lime-stabilized base course, and making soil borings into the underlying subgrade soil.

Construction History

Chino Airport, CA. Chino Airport is located in San Bernardino County and is operated by the County Department of Airports. It consists of two runways, 3-21 and 8-26, which are 6,200 feet and 3,850 feet long. The airport elevation is 652 feet. Chino Airport was originally a World War II air base and many of the buildings and pavements in use today were constructed at that time. A modernization program has led to construction of new hangars, ramps, taxiways, and upgrading of other facilities.

The Chino Airport pavements evaluated in this report are Taxiways 3-21 and 8-26 as shown in Figure 1. The northerly section of Taxiway 3-21 and all of Taxiway 8-26 were constructed in 1969. The design section for these areas was 2.0 inches of asphaltic concrete, 16.0 inches of lime-stabilized soil base course, and 9 inches of compacted subgrade. The southerly portion of Taxiway 3-21 was constructed in 1971 with design section consisting of 3.0 inches of asphaltic concrete, 13.0 inches of lime-stabilized soil base course, and 24 inches of compacted subgrade soil.

Big Bear Airport, CA. Big Bear Airport is also located in San Bernardino County and is operated by the County Department of Airports. It consists of one runway, 7-25 and associated taxiways and ramps. Runway 7-25 is 5,850 feet long and is at an elevation of 6,748 feet above sea level. The pavements evaluated in this report were constructed in 1973 with a design section of 3.0 inches of asphaltic concrete, 11.0 inches lime-stabilized base course, and 24 inches of compated subgrade soil. Additional taxiway and ramp pavements were under construction in 1978 using the same design section, however, these sections are not included in the evaluation. The pavements evaluated are shown in Figure 2.

Payson, AZ. Payson Airport is located in Gila county approximately 75 miles northeast of Phoenix. The airport consists of 4,900 foot long runway 6-24, aircraft turnarounds at each end, and an aircraft parking apron. The airport elevation is 5,195 feet. All pavements at Payson Airport were constructed in 1975 using a design section of 2.0 inches of asphaltic concrete, 12.0 inches of lime-stabilized soil over variable thickness of compacted subgrade. The layout of Payson Airport is shown in Figure 3.

Climatological Data

Climatological data was obtained from the National Climatic Center of the National Oceanic and Atmospheric Administration. The closest weather station to Chino Airport is the California Polytechnic University, Pomona campus, approximately five miles away, and that data is given in Table 2a. Chino Airport is in a mild, semi-arid area with lowest recorded temperatures in the high 20's and summer temperatures occasionally over 100°F. In 1978 the lowest temperature recorded was 26°F and the highest was 109°F. Normal rainfall is 16.45 inches per year and only rarely does snow occur.

Big Bear Airport, although only 50 miles from Chino, has a completely different climate due to its elevation, 6,748 feet above sea level. Big Bear experiences temperatures below 0°F and substantial snowfall. In 1978 the lowest temperature recorded at Big Bear was 3°F and the highest was 89°F. A summary of weather data from Big Bear is given in Table 2b.

Payson Airport lies on the south slope of the Mogollon Plateau and is exposed to storms that enter Arizona from the west in winter and the south in summer. This accounts for the relatively high amount of precipitation compared to the low-lying desert areas of Arizona. Approximately one-fourth of Payson's winter precipitation is snow. The lowest temperature for the period of record was -15°F and the highest was 107°F. A summary of weather data is given in Table 2c.

Aircraft Traffic Data

All three airports evaluated are general aviation airports and are used by many types of aircraft. Detailed records of types of aircraft using each airport are not maintained, however, observations of the types of aircraft using each airport during the field phases of this investigation were recorded and are summarized in Table 3. Also provided are the total numbers of departures for a one-year period and maximum takeoff weights for each aircraft (Ref 3). Big Bear and Payson do not have full-time air traffic control thus the numbers of operations for these airports do not include flights occurring when airport facilities were not manned.

Soil Sampling and Core Borings

The pavements at each airport were cored to obtain samples of the lime-stabilized soil and underlying subgrade soil. Three 6-inch diameter cores of the base course were obtained at each location and an auger boring was made to a depth of 6 feet below the pavement surface. In addition approximately 1000 lbs of native soil was obtained for use in detailed laboratory testing. All of the samples were returned to the Civil Engineering Laboratory for testing. The locations of core and auger borings are shown for each airport in Figures 1, 2 and 3. Logs of the borings and classification of subgrade soils are summarized in Appendix A.

Surface Deflection Measurements

Surface deflection measurements were made using a Benkelman Beam and a loaded dump truck. The dump truck was loaded to provide a 18,000 lb axle load with dual 10:00x20:00 tires. The deflection measurements were made on a grid pattern at each airport as shown in Figures 1, 2, and 3. The test procedure at each location consisted of placing the tip of the Benkelman Beam between the dual wheels, zeroing the dial gauge, then driving the truck forward and recording the elastic rebound of the pavement surface to the nearest 0.001 inch. Temperature readings were made periodically during the measurement period. The Benkelman Beam is shown in use at Big Bear Airport in Figure 4. The results of these measurements are tabulated in Appendix B.

Visual Condition Survey

At each airport the author made a walking survey of each facility being evaluated. Pavement defects were noted and photographed. Some locations were marked for detailed testing by coring and discussions were held with airport, design, and construction personnel to determine causes for defects. The results of these surveys are provided in the following narratives.

Chino Airport, Taxiway 3-21. The overall condition of this taxiway was excellent. The easterly portion which was constructed in 1969 had some minor alligator cracking as shown in Figure 5. These areas also had higher deflections when tested with the Berkelman Beam indicating a slightly weaker pavement section. An occasional transverse or longitudinal crack was also found in this area. These cracks were generally less than 1/4-inch wide.

The westerly portion of Taxiway 3-21 constructed in 1971 had only very minor transverse cracks as shown in Figure 6. Approximately 5 of these cracks were found in this area.

Taxiway 8-26.

This section constructed in 1969 was in fair to good condition. Some alligator cracking and slight depressions were noted. Surface deflection measurements in this area also indicated a weather pavement section than Taxiway 3-21.

Big Bear Airport. Runway and Taxiway 7-25 were constructed in 1973 and with the exception of an area of approximately 6,000 square feet near the 07 end of the runway was in excellent condition. The distressed area was located from station 5+25 to 7+78 and from 3 feet left to 28 feet right of the centerline. The major defects in this area were longitudinal cracks up to 1 inch wide and upheaval of the pavement surface along these cracks. This area is shown in Figures 7 and 8. Repairs were made in this area in August, 1978. During the repairs seams of unmixed lime were found along the cracks and these were believed to be the major cuases of the distress. Some other minor longitudinal cracking was noted one to two feet from the pavement edges. The designers

for this project considered this edge cracking to be caused by not extending the lime-stabilized base course beyond the edge of the asphalt concrete surfacing. On subsequent projects the stabilized layer was constructed 1 to 2 feet wider than the surfacing.

Payson Airport. Runway 6-24 and the adjacent ramp area which were constructed in 1975 were in good condition in 1978. The major defects noted were longitudinal and transverse cracks which had been sealed. Typical cracks found are shown in Figure 9. These cracks are reported to have appeared during the six months after construction which led to concern that the pavement was failing. Investigation by the parties involved in the construction did not elicit a single cause for cracking. Suggested causes were poor mixing of lime, inadequate lime-stabilized layer thickness, curing shrinkage, and expansion of subgrade soil. The cracks, while unsightly, did not impair operation of the aiport. The cracks were sealed and few new cracks subsequently appeared. During the field portion of this investigation, a core was taken of one of the sealed cracks to determine how deep the cracks penetrated. The crack and the coring operation are shown in Figure 10. The core recovered is shown in Figure 11. This crack occurred at a thin section of the lime-stabilized soil, 5.5 inches versus 12.0 inches design thickness. The crack went through the asphalt concrete surfacing and the lime-stabilized soil but did not appear to continue into the subgrade. The thinner than design section appeared to function as a weakened plane joint which allowed shrinkage cracks to occur.

Other minor defects noted during the visual survey were unrelated to lime-stabilization and included bleeding of the asphalt surfacing in some paving lanes (Figure 12) and slight raveling of the surface.

Analysis of Field Testing

Lime-Stabilized Layer Thickness. All three airports showed variations in lime-stabilized layer thicknesses and almost all cases were thinner than the design section. The borings in Appendix A show deficiencies in layer thickness at Chino Airport of 1 to 6 inches, at Big Bear from 0.5 to 4.3 inches, and at Payson 0 to 8.1 inches. Discussions with engineers involved in the design and construction of these airports concluded that loss of grade stakes or hubs during mixing operations contributed to this variance in depth. One method suggested to avoid this problem is to test thickness of lime application and mixing prior to compaction and determine elevations of each test location. The elevation of the bottom of the stabilized layer can be compared with design elevations at that point and deeper mixing can be accomplished if required. Merely measuring the thickness of the uncompacted lime-stabilized layer is not adequate since some lime-stabilized soil could be removed during compaction and final grading operations. The contractor performing stabilization at Big Bear in 1978 graded and compacted the native soil to a fraction above finished lime-stabilized grade before applying and mixing the lime. This procedure seemed very effective. Extra caution must be used in stiff clays as at Payson where the stabilization equipment may have difficulty reaching full depth. Tests of the thickness of the lime stabilized layer should be made again after mixing, compaction, and final grading. Depth of lime treatment can be qualitatively measured by

spraying the soil with a 5 gm per liter phenolphthalein solution (Ref 4) and observing the color indication. The presence of sufficient lime to stabilize the soil will yield a brilliant red color. This simple, expedient test gives an immediate answer but does not provide direct quantitative data on amount of lime present. Titration procedures for determining quantity of lime in soil are available in American Society for Testing and Materials (ASTM), Vol. 19, Standard Test Method D3155 or American Association of State Highway and Transportation Officials, Test Method T232-70. These methods do require laboratory facilities and do take about one hour per sample to test.

Surface Deflection Measurements

The data from the surface deflection measurements were analyzed and are summarized in Table 4. The data are also plotted in Figures 14 through 18. The plots show a profile of deflection variation longitudinally along the pavement surface. Interpretation of the data supports the variability found in lime-stabilized layer thickness and compressive strength. Coefficients of variability (CV) for the Benkelman Beam data range from 49.0 to 83.0 percent. Yoder and Witczak (Ref 5) give data for deflection measurements on 259 varied highway sections showing a CV range of 5.6 to 55.5 percent. The lime-stabilized section with the lowest CV in Chino Airport, Taxiway 3-21, stations 30+00 to 60+00 with a CV of 49.0 percent and Big Bear Airport was the highest at 83.0 percent. The high CV for Big Bear is partially attributed to the distressed section from station 5+50 to 8+50 which was removed and replaced in Sep 1978. Deleting the test data from that area, however, only lowers the Big Bear CV to 68.4 percent, still very high compared to highway pavement sections. The primary causes of variability in the lime-stabilized sections are felt to be non-uniform mixing of lime and variable thickness of stabilized layers.

To evaluate the load carrying ability of the three airports, the surface deflection measurements were related to load repetitions to failure by using methods from highway technology. Selection of a representative deflection value to use presents a problem. If the arithmetic mean is used an unconservative value may be determined for much of the pavement area due to the wide variations in deflection measurements. To account for this variability, the Asphalt Institute (Ref 6) recommends using the mean deflection plus two standard deviations and the California Department of Transportation (Ref 7) recommends using the 80th percentile value, that is 80 percent of the test values are equal or lower and 20 percent are higher. For this evaluation the mean plus two standard deviations was used as the evaluation deflection to account for the high variability of test data previously discussed. As given in Table 4 the values for the mean plus two standard deviations are substantially higher than the 80th percentile and thus give a more conservative evaluation.

Relating the deflection measurements to pavement performance can be accomplished using the relationship of deflection versus number of equivalent 5,000 lb wheel load applications as used by the California Department of Transportation (Ref 7). The chart shown in Figure 18 is used to evaluate allowable number of 5,000 lb wheel loads using deflection measurement procedures which are identical to that used in this investigation. Although the California method is designed for highway use the

magnitudes of highway loadings are similar to loads on airports designed for light aircraft. For example, an aircraft with a 5,000 lb single wheel main gear load would have a gross aircraft weight of 10,500 lbs assuming 95 percent of the gross weight is carried by the two main gear and 5 percent is carried by the nose gear. This compares favorably with the 12,500 lb design loading used at Big Bear and Payson airports. The pavements at Chino Airport were designed for a gross aircraft loading of 30,000 lbs. However, over 90 percent of the aircraft traffic is under 12,500 lbs gross aircraft weight.

Simplifying assumptions made are that lateral distribution of traffic is not considered and that the criteria for pavement failure would be the same for the airport pavements as for highway pavements. The first assumption is considered conservative as highway traffic is extremely channelized. According to Yoder and Witczak, transverse distribution of highway traffic is approximately 4.0 feet while aircraft traffic on a taxiway is distributed over 14 feet and on a runway up to 64 feet depending on specific aircraft gear configuration. Thus a higher number of aircraft operations is required to stress each point on a pavement than is the case with highways. The second assumption, regarding failure criteria, is less easily defined and for this evaluation it is assumed that the criteria for failure on airport pavements are the same as for highway pavements. The type of aircraft using airports designed for less than 30,000 lbs gross weight are generally less susceptible to foreign object damage and are less influenced by pavement roughness. Therefore, highway failure criteria are reasonable.

Using the previously stated assumptions the number of allowable equivalent 5,000 lb wheel loads was determined from Figure 18 and are tabulated in Table 4. The number of allowable load repetitions varies from 20,000 on Taxiway 8-26 at Chino to over 44 million on Taxiway 3-21, stations 30+00 to 60+00 at Chino. The wide range of results is considered reasonable considering the wide variations in deflections and thickness of stabilized soil layers.

As no records are kept of types or number of aircraft trafficking a pavement area on any of the evaluated airports, quantitatively relating calculated allowable load repetitions to actual performance under traffic is impossible. Qualitatively, however, there appears to be a reasonable relationship between pavement condition and calculated allowable load repetitions. The pavements with the lowest number of calculated allowable loads are Chino Taxiway 3-21 from station 0+00 to 24+00 and Chino Taxiway 8-26. These areas, constructed in 1969, also were the oldest pavements evaluated and showed signs of the beginning of load-associated alligator cracking. Other pavements had some cracking but none was felt to be directly related to traffic, as for example, the shrinkage cracking at Payson Airport and the distressed area caused by unmixed lime at Big Bear.

The design pavement life of flexible pavements meeting FAA standards is usually 20 years (Ref 8). With the exceptions of two areas at Chino Airport, Taxiway 3-21 from station 0+00 to 24+00 and Taxiway 8-26, the other areas tested can be reasonably expected to have at least a 20 year life at current aircraft departure levels and mix of aircraft types. Pavement life, of course, is also related to environmental effects and these are not considered in this analysis.

SECTION III

LABORATORY TESTING

Subgrade Soil Samples

At each airport samples were obtained of subgrade soils from each core location by augering to a minimum depth of 6.0 feet. In addition approximately 1,000 lbs of native soil was obtained from two locations at each airport and designated as Pit 1 and 2. The samples were obtained to provide sufficient material to perform California Bearing Ratio tests and soil-lime mixtures. The soil samples were tested to determine soil classification, moisture content, liquid limit, plasticity index, moisture-density relationship, and California Bearing Ratio (CBR). The test methods used are those recommended by the FAA in Ref 8. The test methods are tabulated in Table 5. The results of subgrade soil sample testing are given in Table 6. The subgrade soils at all three airports were primarily silts and clays with the exception of Big Bear where 4 of the samples were classified as silty sand, SM. These 4 soils were borderline cases with just slightly more than 50 percent retained on the No. 200 sieve. For informational purposes the old FAA soil classifications in use when these pavement sections were constructed are also given in Table 6.

All of the subgrade soils have low CBRs with values ranging from 2 to 4 at 95 percent of maximum density. The samples showed swell after 4 days of soaking ranging from 0 to 0.7 percent. These values are reasonable for the types of soils encountered. The soils are considered excellent candidates for stabilization with lime with the possible exception of the non-plastic SM soils at Big Bear airport.

Lime-Stabilized Base Course Cores

At each of the locations shown in Figures 1 through 3, three cores were taken of the lime-stabilized base course with a 6-inch diameter core barrel. In some locations the 6-inch cores crumbled and fell apart so 4-inch diameter barrels were used in an attempt to obtain useable samples. In spite of these efforts some samples could not be recovered intact in a form suitable for compressive strength testing. The cores obtained were shipped to CEL for laboratory testing to determine unconfined compressive strength and lime content. The results of the compressive strength tests and comments on condition of cores are presented in Table 7.

The erratic results of the compressive strength tests are attributed to possible weakness introduced by the coring operation and to a lesser degree to varying lime content. Where good cores were obtained, compressive strengths ranged from 103 to 416 psi.

The cores and pieces of cores remaining after testing were crushed and representative samples were taken from each location to be used for determination of lime content of the stabilized material. Initial attempts to determine the percentage of lime contained in the cores were made by using ASTM Method D3155-73. This test method is a titration procedure and is used primarily for construction control of lime content of uncured soil-lime mixtures.

The titration gives the amount of calcium (Ca) present in the sample. Since the untreated soil may contain Ca, titration of an untreated sample is necessary to establish a base point for zero added lime. Then at least two different known percentages of lime are added to the soil and then titrated to derive a calibration curve for a specific soil. A curve was established for the soils from each airport and used to measure lime contents in each core location. Three titrations were made for each sample and the results averaged. The percentage of lime in the cores based on these data is felt to be suspect. The percentages are all lower than would be expected and are much lower than design lime contents recorded in the construction records. For example the Big Bear samples based on titration results ranged in lime content from 0 to 3.1 percent when the design lime content was 4.0 percent quicklime. The samples from the other fields were equally erratic and suspect. Possible causes of the erratic and probably erroneous results were the age of the cores at the time of testing, difficulty in obtaining representative samples from the cores, and variation in actual lime content.

An attempt was made to test the lime-stabilized samples using the X-ray energy dispersive analysis capability of CEL's scanning electron microscope (SEM). Samples of untreated soil and portions of lime stabilized cores were ground to a fine powder and pressed onto the end of an aluminum rod. The rod was placed in the SEM and the X-ray spectrum determined. Examples of these spectra are shown in Figure 19 for an untreated soil and a core sample from Payson Airport. These spectra give only a qualitative measure of lime content as expressed by the height of the calcium (Ca) portion of the spectrum. All of the samples tested in this manner showed core samples to contain more calcium than the untreated soil samples. Further attempts to better quantify lime contents were discontinued.

No testing of cores was made to determine potential for damage by frost action. Big Bear and Payson airports both sustain some ground freezing at the depths where the lime-stabilized soil layers were placed; however, no damage or pavement distress which could be attributed to frost or freezing damage was noted.

Laboratory Lime-Stabilized Soil Samples

The untreated soil samples from each airport were used to evaluate procedures that would yield optimum lime content, highest unconfined compressive strength, and greatest resistance to frost damage. Review of the literature led to using the processes subsequently described. These methods are felt to provide adequate design data with resources that are available to most geotechnical engineers and testing laboratories. In addition to the conventional tests, resilient modulus tests of lime-stabilized and native soil were made to evaluate increases in modulus with stabilization.

Optimum Lime Content

The method developed by Eades and Grim (Ref 9) uses the pH of the soil-lime mixture as the indicator of sufficient lime content to sustain a strength producing lime soil pozzolanic reaction. The required pH of the lime-soil mixture is 12.40. Samples of soil are mixed with various percentages of lime covering a range generally of 2 to 6 percent.

Distilled water is added to the soil and the samples agitated. After one hour the pH of the lime-soil slurry is measured with a pH meter or pH indicating paper. The lowest percentage of lime that gives a pH of 12.40 is the amount required for stabilization. Some soils due to mineralogical composition will not achieve a pH of 12.40 so for these the lime content which gives a pH of 12.30 is used. With the exception of the pit No. 1 sample from Big Bear Airport all of the soils tested for this investigation achieved a pH of 12.40 with reasonable lime contents. Optimum lime contents as determined by this test procedure ranged from 4.0 to 6.0 percent using hydrated lime. The results of the one hour pH tests of the lime-soil slurries are given in Table 9. The properties of the hydrated lime use for these and all subsequent laboratory lime-soil mixtures are given in Table 10.

Unconfined Compression Strength

The most common test used to evaluate strength is the unconfined compression test. This test was used to measure increased strength obtained by addition of lime to soil samples from the three airports in this study. Before compaction of the samples, the maximum density and optimum moisture content for each soil with the predicted optimum lime content was determined. FAA Test Method T-611 was used for this test. As is usually true the lime-stabilized soil mixtures had lower maximum densities and higher optimum moisture contents than the same soils without lime. Sample preparation procedures for all samples consisted of mixing the soil, lime, and water and then placing in a sealed container four 24 hours. The sample was then compacted in the standard 1/30 cubic foot mold for the moisture/density relationship or the Harvard Apparatus for unconfined compression testing. Results of the moisture/density tests for both unstabilized and stabilized soils are given in Table 11.

The samples constructed for unconfined compression testing were compacted to obtain dry densities for each soil which were as close as possible to the maximum densities given in Table 11. Specimens were compacted at lime contents of 0, optimum as determined by the pH test, and 2 percent above and below optimum. Three samples were compacted for each lime content and the samples were wrapped in saran and aluminum foil to prevent moisture loss during curing. A partially wrapped sample is shown in Figure 20.

The wrapped samples were cured using two methods, a conventional method and an accelerated curing method to allow shorter testing times. The samples cured conventionally were placed in controlled chamber at $73^{o}F$ and 100 percent relative humidity. The accelerated cure samples were cured in an oven at $120^{o}F$ for 30 hours. Dunlap and Biswas (Ref 10) have shown correlation between the two curing techniques and accelerated curing would be desirable in construction control testing.

After curing the samples were unwrapped and were weighed before testing in unconfined compression. The samples were loaded at a strain rate of 0.05 in/min. After the samples were tested they were oven dried and moisture content and dry density were calculated. The results of these tests are shown in Figures 21 through 26. Each data point represents an average of three individual samples. A linear relationship between accelerated and 28-day curing was assumed and the data points are plotted in Figure 27. A good correlation exists for the soils

tested in this investigation and coupled with correlations found in Ref 10 it is felt that accelerated curing of stabilized samples is reasonable and that accelerated curing can be used for design and quality control.

Thompson has suggested the soils which show an increase in compressive strength of 50 psi or greater when treated with lime and compred to untreated soil be considered reactive and suitable for stabilization (Ref 11). Only the Pit 1 sample from Big Bear Airport of the soils in this investigation did not gain at least 50 psi in strength. The Payson samples showed the greatest strength gain, 284 and 80 psi, which is predictable since these soils have the highest percentage of clay.

The unconfined compressive strength tests also validated the use of the Eades and Grim pH test to determine optimum lime content. Only Chino Airport Pit No. 2 sample had a substantially higher strength at a lime content different than predicted. It is felt to be good practice to bracket the predicted lime content as a verification and the unconfined compression tests are required to demonstrate the ability of soils to react with lime.

Freeze-Thaw Durability Testing

Use of lime-stabilized soil as base course layers requires that they be able to sustain cyclic freezing and thawing without loss of structural integrity. No standard test method exists for evaluating freeze-thaw characteristics of lime-stabilized soils. A promising method which gives a good correlation to the much slower process of freezing and thawing specimens is the vacuum saturation method described by Dempsey and Thompson (Ref 12).

In this method the cured samples are placed in a chamber and subjected to a vacuum pressure of 24 in of mercury for 30 minutes. The chamber is then flooded with de-ionized water and the samples are soaked for one hour at atmospheric pressure. After the soaking period the samples are allowed to drain for two minutes and then are tested for unconfined compressive strength at a loading rate of 0.05 in per minute. In this investigation a triaxial soil testing cell was used as the vacuum chamber and water was introduced from the bottom of the cell. The base plate of the cell with three samples resting on a perforated plate is shown in Figure 28.

Samples of each lime-stabilized soil were prepared at predicted optimum lime contents and cured using the accelerated method, oven curing for 30 hours at 120^{o}F. The samples were then vacuum saturated as previously described. The results of these tests are plotted on Figures 20 through 25. Loss of strength compared to unsaturated samples ranged from 51 percent for Chino Pit No. 2 to 10.7 percent for Payson Pit No. 3. When a lime-stabilized soil layer is to be exposed to freeze-thaw conditions it is recommended that samples be tested using the vacuum saturation method and the residual strength should meet criteria to be explained later in this report.

Resilient Modulus Tests

The resilient modulus, M_r, was determined for native and lime-stabilized soil samples using a repeated-load triaxial compression test

method as detailed in Ref 13. Samples of native and lime-stabilized soil were compacted in a 2.8 by 6.0 inch mold at optimum moisture content and to maximum density as previously determined by the FAA T-611 test method. The lime-stabilized samples were cured for 30 hours at 120°F before testing. To conduct the actual resilient modulus test the sample was placed in a triaxial cell and a confining pressure of 2 psi applied. A cyclic deviator stress was applied with a loading frame equipped with an air piston for applying the load. A function generator was used to control loading rate and the load was applied using a sinusoidal wave form and a frequency of 1 hertz. Axial strain of the sample was measured with a linear variable differential transformer. The sample was stressed by applying 200 load repetitions at deviator stresses of 3, 6, and 9 psi. Then the deviator stress was reduced to 6 psi and 200 more load repetitions were applied. The resilient modulus, M_r, is equal to the deviator stress divided by the axial strain at end of the 800 total load repetitions.

The lime-stabilized samples gave M_r values ranging from 9,950 psi for Big Bear Pit No. 1 to 33,848 psi for Chino Pit No. 2. The untreated soils ranged from 3,029 psi for Chino Pit No. 1 to 6,179 psi for Payson Pit No. 1. The values obtained are summarized in Table 12. The increased strength as evidenced by higher modulus values generally follows the same pattern as strength increases with unconfined compression data. Insufficient data points were collected to attempt a correlation of M_r values with unconfined compression strength. M_r values can be used in layered elastic analysis of pavement sections and in some design procedures.

The M_r values obtained for the lime-stabilized soil are in the lower range of values expected of unbound granular materials. Yoder and Witczak (Ref 5) suggest an average granular M_r of

$$M_r = 9{,}600\ s_3^{\ 0.55}$$

where s_3 = confining stress. For the confining stress used, 2 psi, this formula yields a modulus of 14,100 psi which compares favorably with the values obtained. Thus it appears that based on M_r values, the lime-satabilized soil layers are approximately equivalent to granular subbase materials.

DISCUSSION AND CONCLUSIONS

The ability to utilize on-site native soil to the maximum extent possible when constructing an airport pavement is attractive to the designer, the airport owner, and the taxpayers. The three airports studied in this investigation afforded a unique opportunity to evaluate use of one method, lime-stabilization, of using on-site native soil in a pavement layer which would have normally required importation of a select material at a greater cost.

Although it was not possible to determine the exact type or amount of aircraft traffic the pavements have been able to support, it is concluded from the condition surveys, the pavement deflection data, and the cores of lime-stabilized soils that the pavements have performed acceptably. The exceptions are the section at Big Bear Airport which required repair and the shrinkage cracks at Payson Airport which required sealing.

The one factor which is apparent to some degree at all three airports is the variability of the stabilized layer thicknesses, compressive strength, and surface deflections. Some of this variation is attributable to the inherent variability of soils and to normal construction variations. However, as was pointed out in the section on surface deflection measurements, the variations were greater than normally found in pavements. This suggests a need for better quality control of the construction. Some suggested improvements are a minimum design stabilized layer of 12 inches, determining lime content by using ASTM procedure D3155-73, measuring the thickness of stabilized layers after final grading, and using a test for mixing efficiency. These improvements are included in a proposed specification in Appendix C.

Laboratory testing of the native and lime-stabilized soils showed that all the soils at these airports benefited from lime-stabilization with the possible exception of Big Bear Airport Pit No. 1. All of the samples except Big Bear Pit No. 1, when cured for 30 hours at 120°F, had unconfined compressive strengths in excess of 80 psi. The performance of the pavements constructed with these soils suggests that a criterion of a minimum unconfined compressive strength of 80 psi be used to determine suitability of lime-stabilized native soil for base course. Since virtually all the aircraft traffic using the pavements at the three airports under consideration in this report were under 12,500 lbs gross weight it is felt to be imprudent to extend this method of soil stabilization to base course uses for aircraft in the 12,500 to 30,000 lb range at this time.

Where pavements will be subjected to freeze-thaw action, samples should be tested after vacuum saturation using the procedure previously described. A minimum compressive strength of 70 psi after vacuum saturation is suggested for determining potential durability of lime-stabilized soils.

In summary, the use of lime-stabilized soil as base course for light aircraft weighing under 12,500 lbs appears feasible and effective. Quality control of construction needs improvement, minimum design strengths are suggested, and a suggested specification is given.

RECOMMENDATIONS

Based on the performance of pavements utilizing lime-stabilized soil for base course at Chino, Big Bear, and Payson airports it is recommended that this construction method be included in Federal Aviation Administration design criteria. Periodic monitoring of the long-term performance of these pavements may provide useful information on the life expectancy of this type of construction and is recommended. Further investigation is required into the use of lime-stabilized soil as base course for aircraft weighing between 12,500 and 30,000 lbs. A suggested approach would be to perform a theoretical design using layered-elastic analysis and then build test sections and subject them to traffic to validate the designs.

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Table 1. Summary of Testing and Data Collection

Field Testing	Laboratory Testing
Construction History	Subgrade Soil
Climatological Data	Classification
	Moisture Content
Aircraft Traffic Data	Frost Susceptibility
	California Bearing Ratio
Core Base Course	Swell
Surface Deflection Measurements	Lime-Stabilized Base Course
Visual Condition Surveys	Lime Content
	Unconfined Compressive Strength
	Frost Susceptibility
	Laboratory Lime-Soil Mixtures
	Optimum Lime Content
	Unconfined Compressive Strength
	Frost Susceptibility

Table 2a. Climatological Data for Chino Airport*

Month	Temperature Means			Precipitation	
	Daily Maximum**	Daily Minimum**	Monthly Average	Monthly for 1978	Normal Monthly
Jan	61.5	40.8	52.1	11.04	3.39
Feb	65.9	45.8	54.1	8.24	2.93
Mar	67.8	45.7	56.1	11.87	2.74
Apr	75.2	47.0	60.3	1.93	1.60
May	76.6	52.2	64.8	0.00	0.25
Jun	87.0	57.0	69.6	0.00	0.05
Jul	88.7	58.6	76.0	0.00	0.02
Aug	87.1	60.2	76.1	0.01	0.05
Sep	94.1	60.1	73.4	1.50	0.19
Oct	79.1	52.7	66.1	0.20	0.42
Nov	74.5	44.5	58.2	2.31	2.10
Dec	65.1	38.4	52.9	2.87	2.71
			Total	39.97	16.45

*Data from nearest recording station, California Polytechnic University, Pomona, approximately 5 miles from Chino Airport.

**Data for period Jan-Dec 1978.

Table 2b. Climatological Data for Big Bear Airport, CA

Month	Temperature Means			Precipitation	
	Daily Maximum	Daily Minimum	Monthly Average	Monthly for 1978	Normal Monthly
Jan	41.4	14.2	Not Available	9.77	Not Available
Feb	46.4	16.3		9.26	
Mar	49.0	22.8		11.04	
Apr	58.7	26.9		3.58	
May	65.4	35.8		0.35	
Jun	76.0	43.3		Trace	
Jul	81.0	46.5		0.08	
Aug	75.9	45.6		0.03	
Sep	76.7	43.7		0.48	
Oct	67.4	35.7		0.18	
Nov	53.5	25.4		3.26	
Dec	43.8	16.0		5.66	
			Total	47.0	

Table 2c. Climatological Data for Payson Airport, AZ*

Month	Temperature (^{o}F)			Precipitation	
	Daily Maximum	Daily Minimum	Monthly	Mean	Snow, Sleet, Hail Mean
Jan	53.1	23.7	38.4	2.11	6.7
Feb	57.2	25.8	41.5	1.43	4.4
Mar	61.4	28.4	44.9	1.78	4.4
Apr	70.0	34.7	52.4	0.96	0.6
May	79.0	41.2	60.1	0.43	T
Jun	88.9	49.0	69.0	0.50	T
Jul	92.5	58.5	75.5	3.10	T
Aug	89.2	57.0	73.1	3.30	T
Sep	85.2	49.8	67.5	1.86	T
Oct	75.5	40.0	57.8	1.64	0.1
Nov	63.3	30.5	46.9	1.45	1.9
Dec	55.2	24.5	39.9	2.21	7.0
			Total	20.77	25.1

*Record period 1948-1970

Table 3. Aircraft Traffic Summary

Annual Departures		Airport		
Types of Aircraft	Maximum Take Off Wt.*	Chino 218,252	Big Bear 3,468	Payson 5,000**
Beechcraft 23	2,450	X	X	
V-35	3,400	X	X	X
F-33	3,050	X		
F-33A	3,400	X		
B-55	5,100	X	X	
E-55	5,300	X		
18	9,900	X		
Cessna 150	1,600	X	X	X
170	2,200	X		
172	2,300	X	X	X
177	2,500	X		X
182	2,950	X		X
207	3,800	X		
210	3,800	X	X	X
310	5,100	X	X	X
Piper PA-18	1,500	X		X
PA-22	1,800	X	X	X
PA-24	2,550	X	X	X
PA-28	2,400	X	X	
PA-23	3,600	X	X	
PA-30	3,600	X		X
Navion G-1	3,315	X		X
Rockwell 500	6,500	X		
Dehaviland DHC-6	12,500	X		X
Douglas DC-3***	25,200	X		
Convair 340***	47,000	X		

*From Reference 3.
**Estimate by Fixed Base Operator
***Occasional use only-not a factor in performance

Table 4. Summary of Surface Deflection Measurements

Location	Number of Measurements	Mean Deflection (0.001 in.)	Maximum Deflection (0.001 in.)	Minimum Deflection (0.001 in.)	Standard Deviation, S (0.001 in.)	Coefficient of Variability %	80th Percentile (0.001 in.)	Mean + 2S (0.001 in.)	Allowable 5,000 lb load Repetitions* ($X10^6$)
Chino Airport									
Taxiway 3-21									
0+00-24+00	101	19.2	74.0	1.0	14.7	76.5	28.0	48.6	0.18
30+00-60+10	107	8.3	20.0	0.0	4.1	49.0	11.0	16.5	44.7
Taxiway 8-26									
0+00-8+00 and 15+00-25+00	73	29.8	80.0	1.0	16.5	55.4	38.0	63.0	0.02
Big Bear Airport									
Runway 7-25 and Taxiway 7-25	239	13.5	80.0	1.0	11.2	83.0	17.0	36.0	0.32
Payson Airport									
Runway 6-24, Taxiways, and Parking Apron	223	18.2	70.0	4.0	11.1	61.0	23.0	40.0	0.28

NOTE: All tests made with Benkelman Beam using 18,000 lb axle load on dual wheels.

*Based on Figure 18 using mean + 2s deflection.

Table 5. Test Methods for Subgrade Soil Samples

Test	Test	Method
Particle-Size Analysis of Soils	ASTM	D-422
Plastic Limit of Soils	ASTM	D-424
Liquid Limit of Soils	ASTM	D-423
Plasticity Index of Soils	ASTM	D-424
Moisture-Density Relations of Soils	FAA	T-611
Bearing Ratio of Laboratory-Compacted Soils	ASTM	D-1883
Classification of Soils for Engineering Purposes	ASTM	D-2487

Table 6. Summary of Subgrade Soil Data

Location	Classification FAA	Classification USC	Field Moisture Content (%)	Liquid Limit	Plasticity Index	Maximum Density (pcf)	California Bearing Ratio (@ 95%)	Swell After 4 Days Soak (%)
Chino Airport								
Taxiway 3-21								
5+00	E-6	ML	4.3	32	6	---	---	---
13+00	E-6	SM	3.3	---	N.P.	---	---	---
45+00	E-6	ML	5.9	35	7	---	---	---
55+20	E-7	ML	4.8	37	11	---	---	---
Taxiway 8-26								
5+00	E-6	ML	4.8	---	N.P.	---	---	---
Pit 1	E-6	ML	5.6	---	N.P	85.9	3	0.0
Pit 2	E-6	CL	3.6	29	8	108.5	2	0.7
Big Bear Airport								
Runway 7-25								
6+00	E-6	ML	3.2	---	N.P.	---	---	---
10+00	E-7	CL	5.3	37	15	---	---	---
25+00	E-5	SM	1.8	---	N.P.	---	---	---
40+00	E-6	SM	2.4	---	N.P.	---	---	---
50+00	E-5	SM	2.0	---	N.P.	---	---	---
Pit 1	E-5	SM	2.4	---	N.P.	114.2	2	0.0
Pit 2	E-6	CL	5.4	30	8	108.6	2	0.4
Payson Airport								
Runway 6-24								
9+00	E-10	CH	6.6	60	37	---	---	---
19+00	E-6	CL	2.7	23	8	---	---	---
29+00	E-7	CL	2.8	33	16	---	---	---
38+65	E-8	CH	5.9	55	32	---	---	---
49+00	E-7	CL	5.7	39	23	---	---	---
Pit 1	E-8	SC	4.7	40	22	109.4	4	0.5
Pit 2	E-8	CL	5.7	49	31	104.8	2	0.1

Table 7. Summary of Strengths and Condition of Lime-Stabilized Base Course Cores

Location	Condition of Recovered Cores	Average Unconfined Compressive Strength (psi)
Chino Airport		
Taxiway 3-21		
5+00	Suitable for test	269
13+00	Only one core tested, others crumbled	68
45+00	All cores cracked vertically before testing	---
55+00	Suitable for test	115
Taxiway 8-26		
5+00	One core split in two horizontally, others tested	137
Big Bear Airport		
Runway 7-25		
6+00	Distressed area, cores crumbled	---
10+00	Cores crumbled	---
25+00	Cores broken into two or more pieces	---
40+00	Good cores	416
50+00	Good cores	126
Payson Airport		
Runway 6-24		
9+00	Good cores	236
19+00	Good cores	103
25+00	Broke horizontally at compaction plane, too short to test	---
38+65	Crumbled	---
45+00	Broke into two or more pieces before testing	---

Table 8. Lime Content of Core Samples by Titration, ASTM D-3155

Location	Lime Content Based on Titration (%)*	Design Lime Content (%)
Chino Airport		
Taxiway 3-21		
5+00	0.3	4.0**
13+00	0.3	4.0**
45+20	0.6	3.0
55+20	0.4	3.0
Taxiway 8-26		
5+00	0.6	4.0**
Big Bear Airport		
Runway 7-25		
6+00	0.0	4.0
10+00	0.2	
25+00	0.0	
40+00	3.1	
50+00	0.0	
Payson Airport		
Runway 6-24		
9+00 (top 6")	2.0	5.0
9+00 (bottom 6")	3.7	5.0
19+00	1.5	5.0
25+00	0.7	5.0
38+65	2.5	5.0
49+00	1.2	5.0

*Percentages not considered reliable, see page 9.

**Type of lime not specified for these locations. All other precentages are quicklime, CaO.

Table 9. One-Hour pH Values of Lime-Soil Mixtures

Lime (%)	Chino Airport		Big Bear Airport		Payson Airport	
	Pit 1	Pit 2	Pit 1	Pit 2	Pit 1	Pit 2
0	8.60	8.60	8.50	7.60	8.50	8.20
2	12.00	12.20	12.20	12.20	12.00	12.10
3	12.20	12.30	12.30	12.30	12.20	12.30
4	12.30	12.40	12.30	12.40	12.30	12.30
5	12.35	12.40	12.30	12.40	12.30	12.35
6	12.40	12.40	12.35	12.40	12.40	12.40
8	12.40	12.40	12.35	12.40	12.40	12.40
10	12.40	12.40	12.35	12.40	12.40	12.40
Predicted Optimum Lime Content	6.0	4.0	6.0	4.0	6.0	6.0

Table 10. Properties of Hydrated Lime Used in Laboratory Testing

Chemical Analysis	Percent
Calcium Hydroxide	94.6
Magnesium Oxide	1.0
Calcium Oxide	Nil
Calcium Carbonate	1.5
Aluminum Oxide	0.5
Iron Oxide	0.1
Physical Analysis	
Specific Gravity	2.23
Sieve Analysis	

Sieve	% Passing
65	100
100	100
150	99
200	97
325	88

Data from supplier, U.S. Lime Co., product data sheet.

Table 11. Maximum Density and Optimum Moisture Contents of Lime-Treated and Untreated Soils, FAA Test Method T-611

Sample	Lime Content (%)	Optimum Moisture Content (%)	Maximum Dry Density (pcf)
Chino Airport			
Pit 1	0	29.6	85.9
	6	30.8	85.4
Pit 2	0	15.9	108.5
	4	19.8	102.1
Big Bear Airport			
Pit 1	0	14.2	114.2
	6	15.5	110.6
Pit 2	0	16.9	108.6
	4	19.8	102.3
Payson Airport			
Pit 1	0	16.4	109.4
	6	22.0	96.4
Pit 2	0	17.5	104.8
	6	22.8	98.0

Table 12. Resilient Modulus Test Results

Sample	Resilient Modulus (psi)	
	Untreated	Lime-Stabilized
Chino Airport		
Pit No. 1	3,029	10,419
Pit No. 2	5,390	33,838
Big Bear Airport		
Pit No. 1	4,664	9,905
Pit No. 2	4,513	19,290
Payson Airport		
Pit No. 1	6,179	17,760
Pit No. 2	5,458	19,950

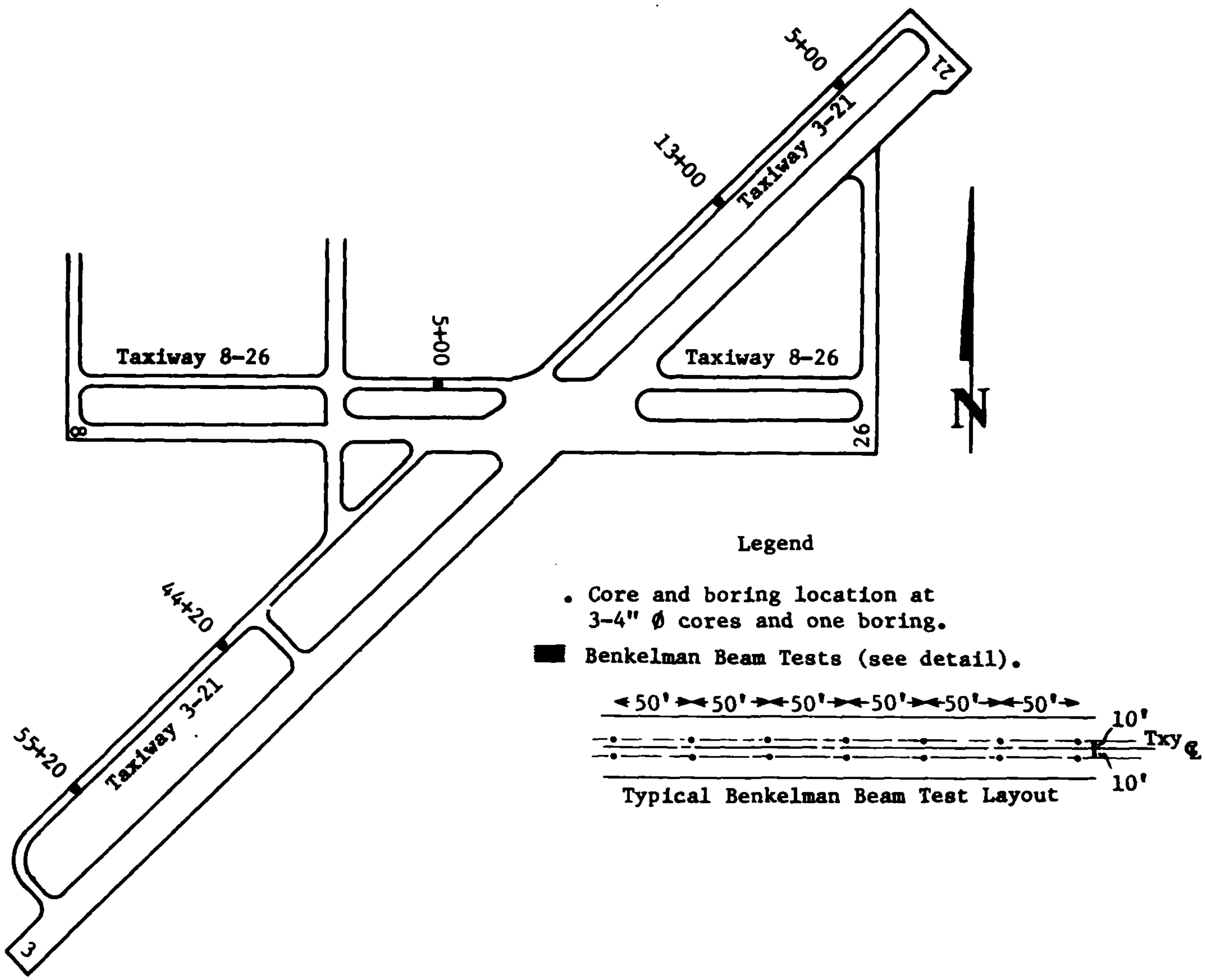
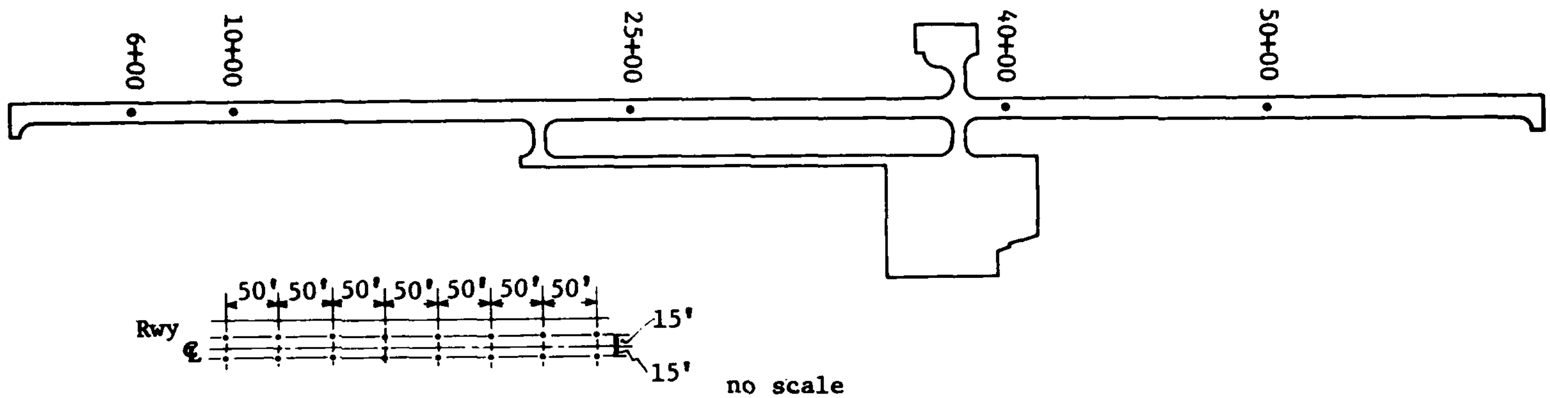


Figure 1. Chino Airport test locations (no scale).

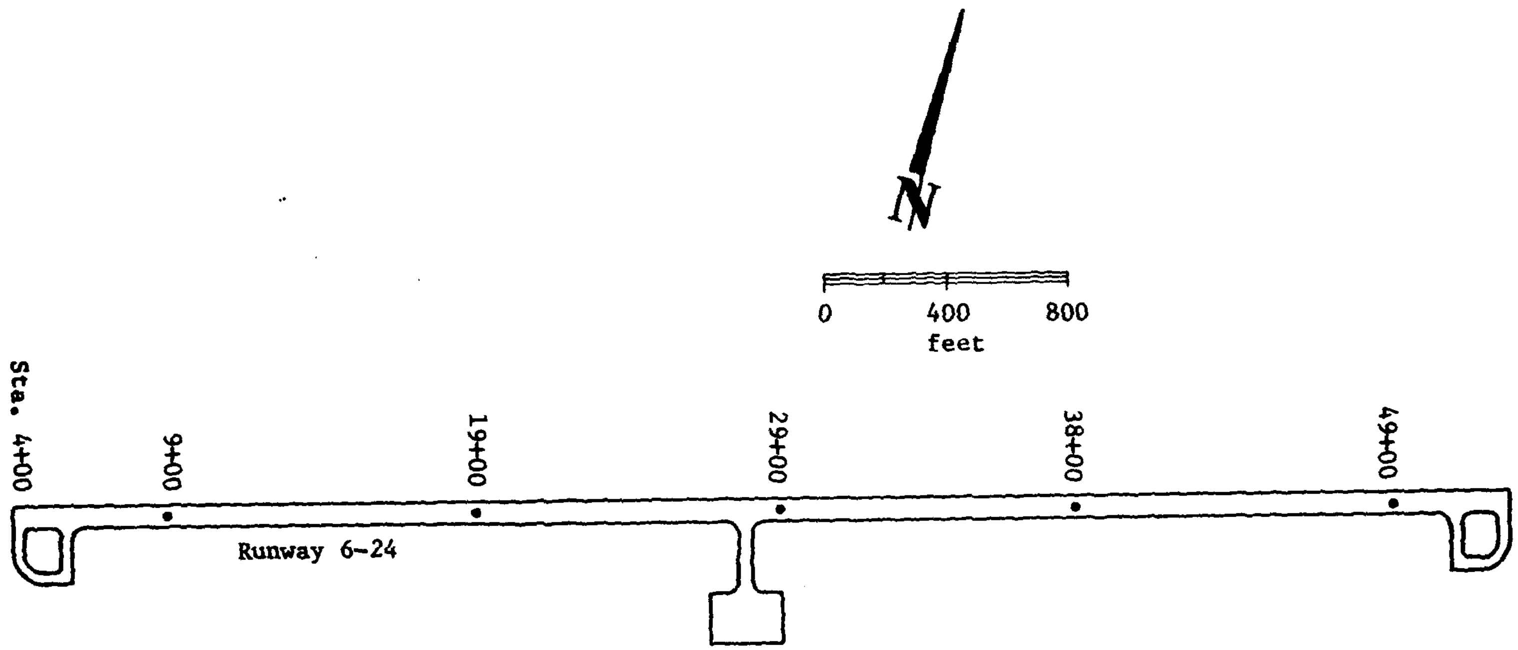


Benkelman Beam Test Grid, begin at Sta. 5+00, end at Sta. 53+80

Test Locations

Core and auger, 3 cores and one auger boring.
• All core locations near ℄, except 6+00 shall be adjacent to a longitudinal crack.

Figure 2. Big Bear City Airport - California - testing layout (no scale).



• Core and auger locations.

Benkelman Beam Tests to cover runway
using *same* grid pattern as Chino tests.

Figure 3. Payson Airport test locations (no scale).

Figure 4. Benkelman beam testing at Big Bear Airport.

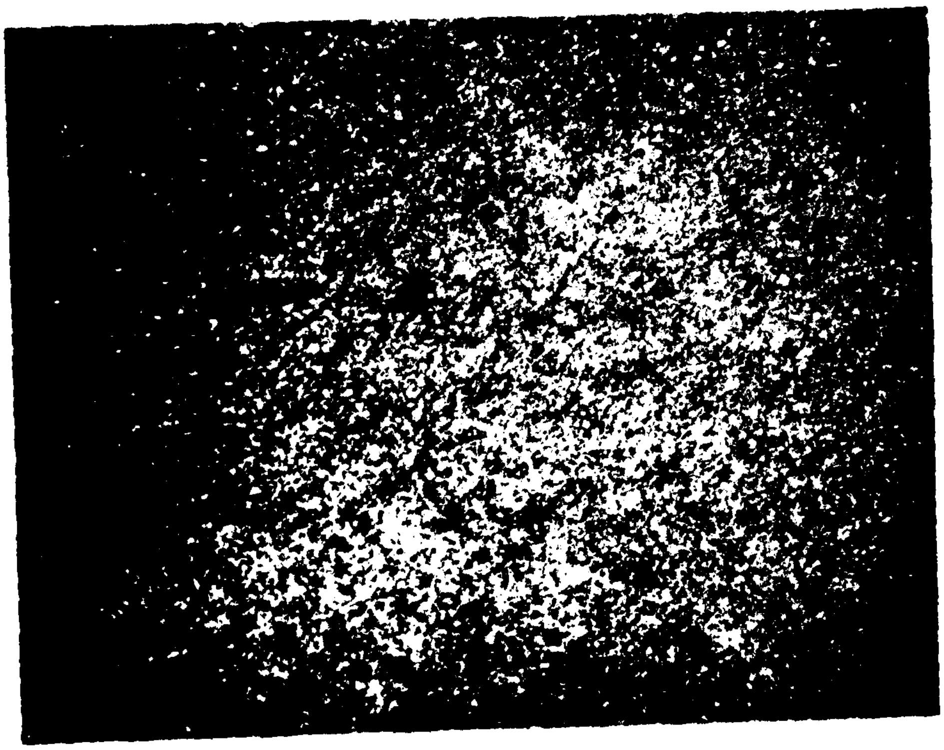


Figure 5. Minor alligator cracking on Taxiway 3-21, Chino Airport.

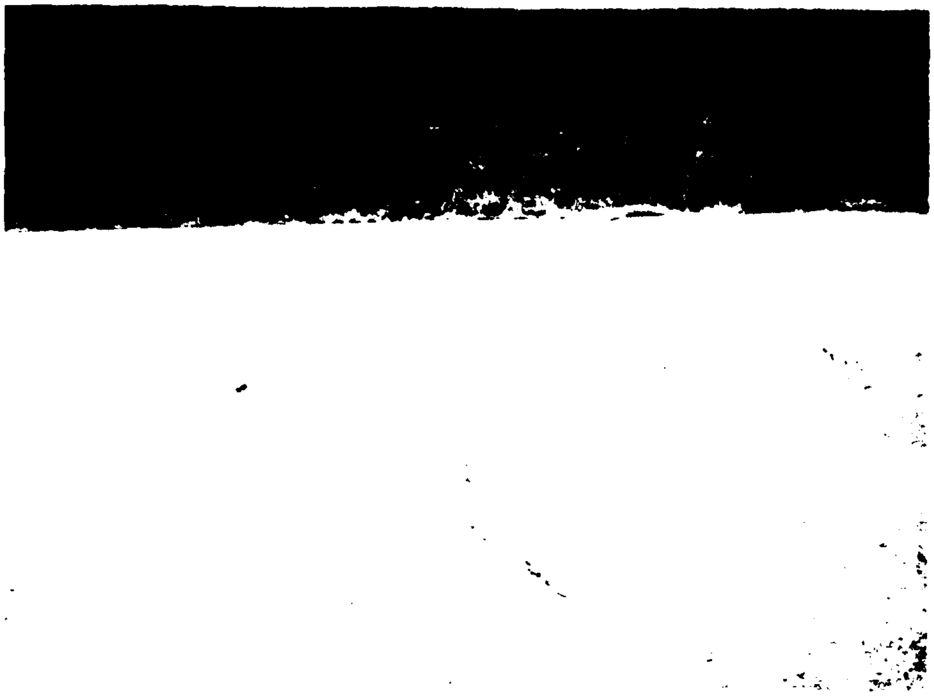


Figure 6. Transverse cracking on Taxiway 3-21, Chino Airport.

Figure 7. Longitudinal cracking in area subsequently repaired, Runway 7-25, Big Bear Airport.

Figure 8. Upheaval along longitudinal crack, Runway 7-25, Big Bear Airport.

Figure 9. Typical cracks in Runway 6-24, Payson Airport.

Figure 10. Crack and coring operation on Runway 6-24, Payson Airport.

Figure 11. Core from crack shown in Figure 10. Note filler full depth of crack and uneven stabilization, Payson Airport.

Figure 12. Bleeding of asphalt in one paving lane, Runway 6-24, Payson Airport.

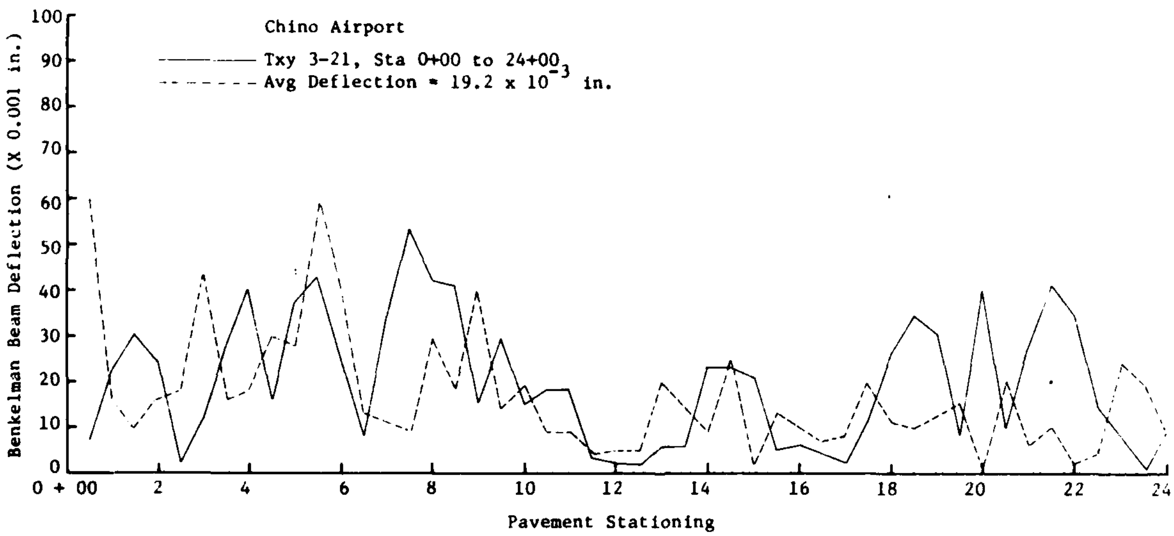


Figure 13. Benkelman beam deflections, Taxiway 3-21, Sta. 0+00 to intersection of Runway 8-26, Chino Airport.

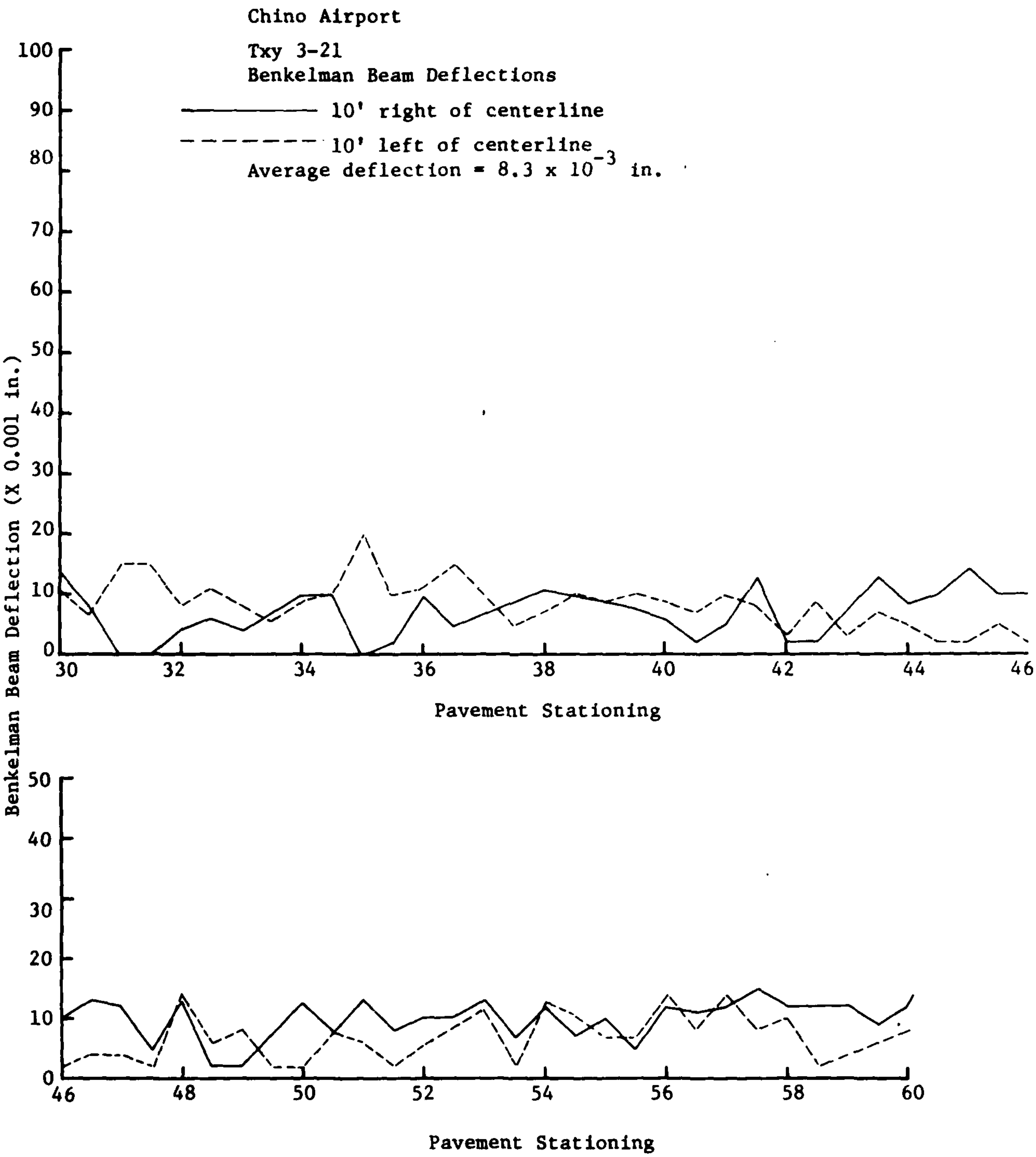


Figure 14. Benkelman beam deflections, Taxiway 3-21, Sta. 30+00 to 60+00, Chino Airport.

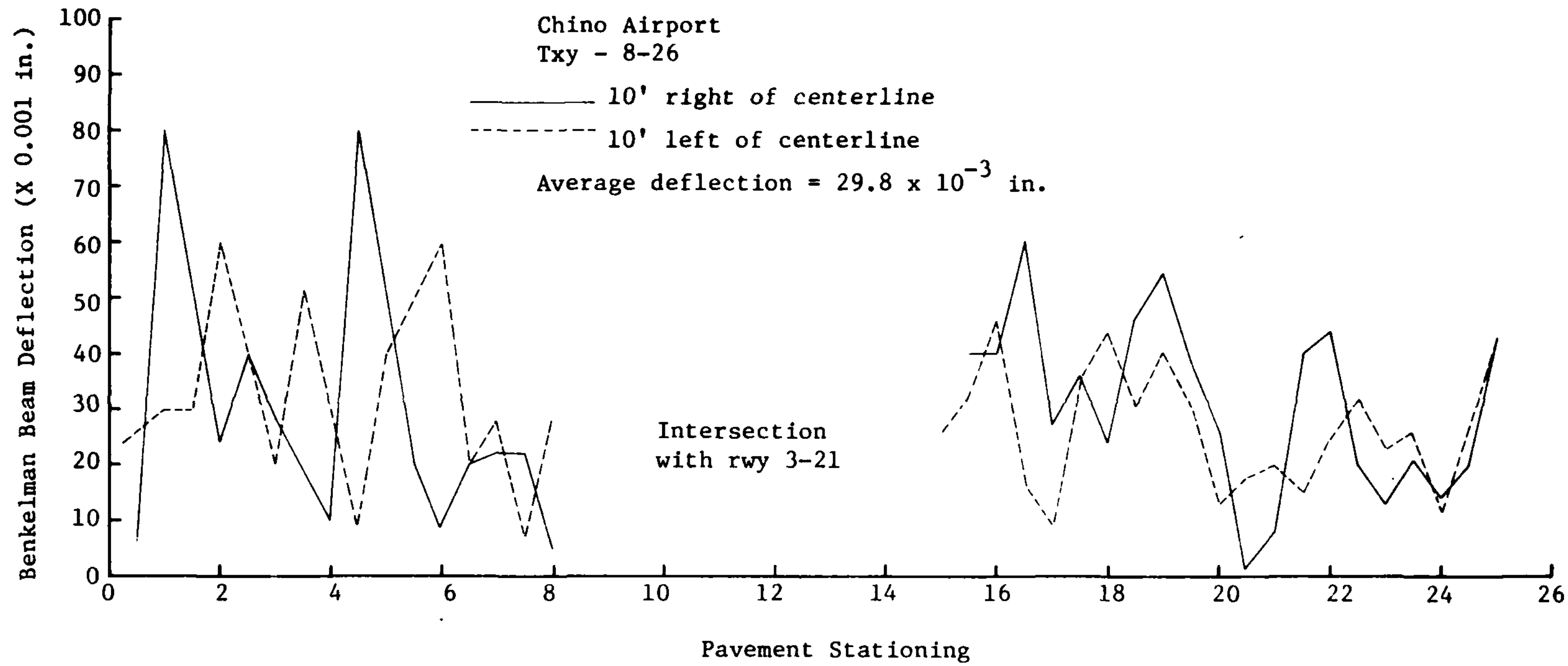


Figure 15. Benkelman beam deflections, Taxiway 8-26, Chino Airport.

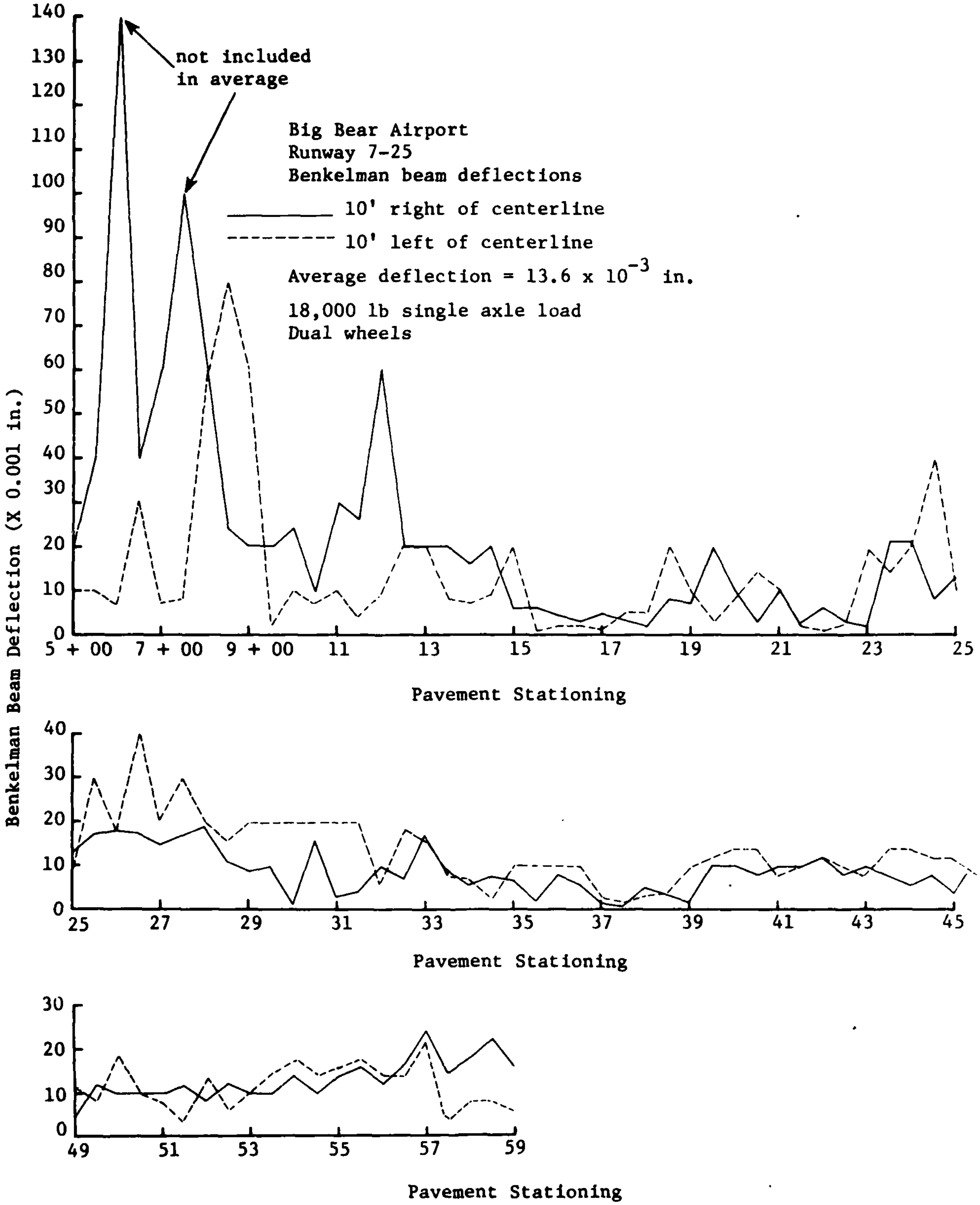


Figure 16. Benkelman beam deflections, Runway 7-25, Big Bear Airport.

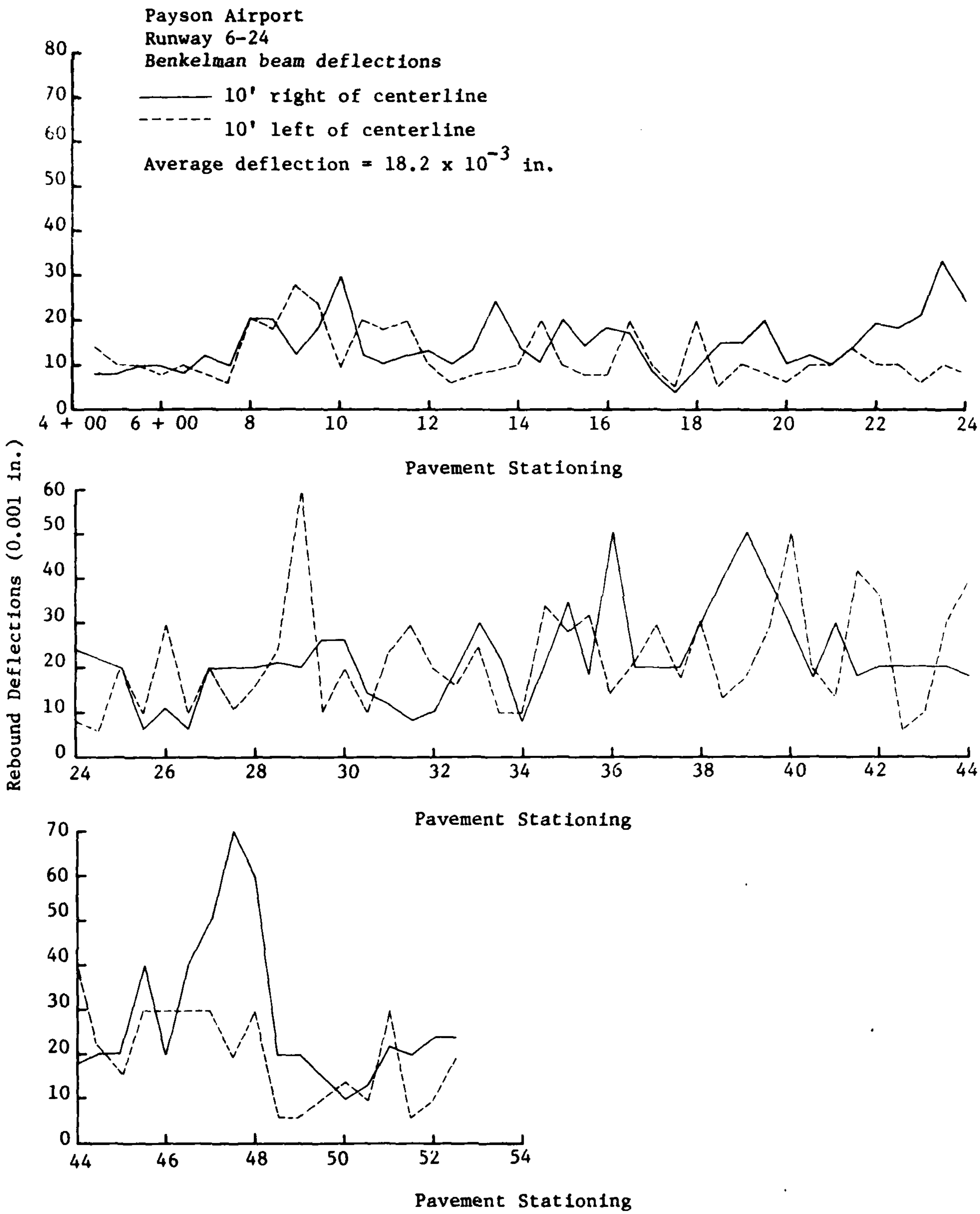


Figure 17. Benkelman beam deflections, Runway 6-24, Payson, Arizona.

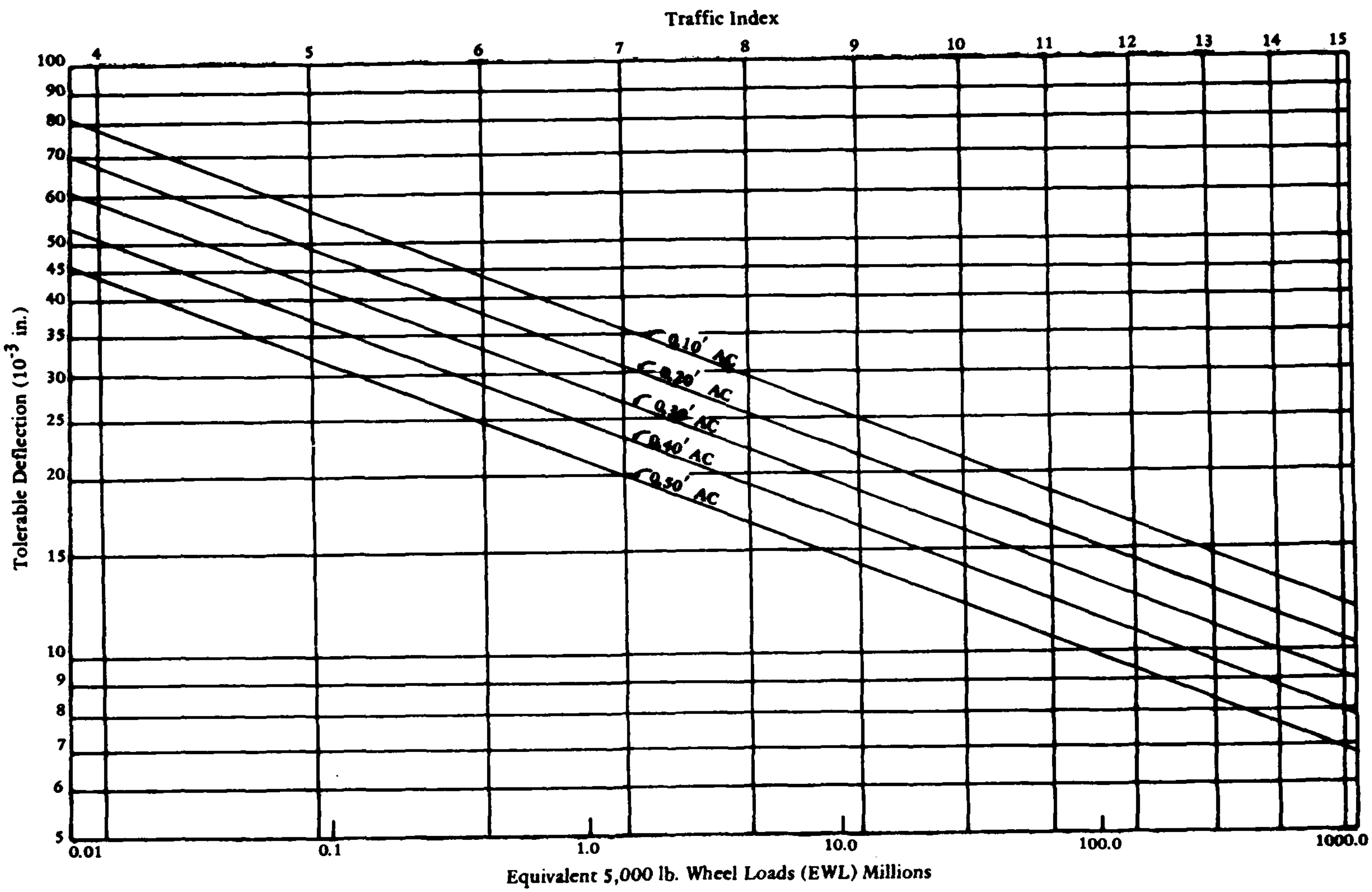


Figure 18. Revised tolerable deflection chart for varying thicknesses of asphalt concrete (Ref 7).

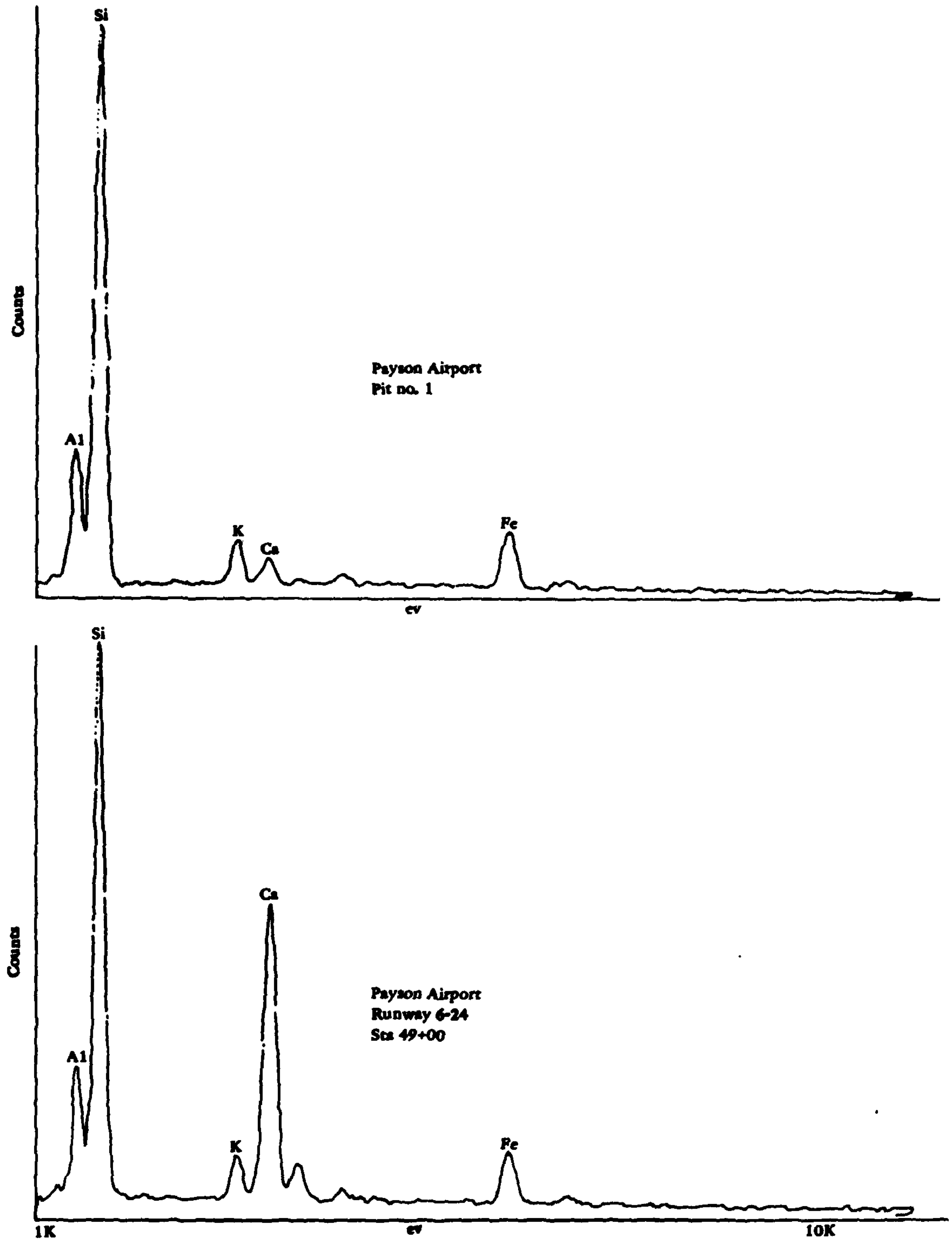


Figure 19. X-ray dispersive analysis curves of treated and untreated Payson Airport soils.

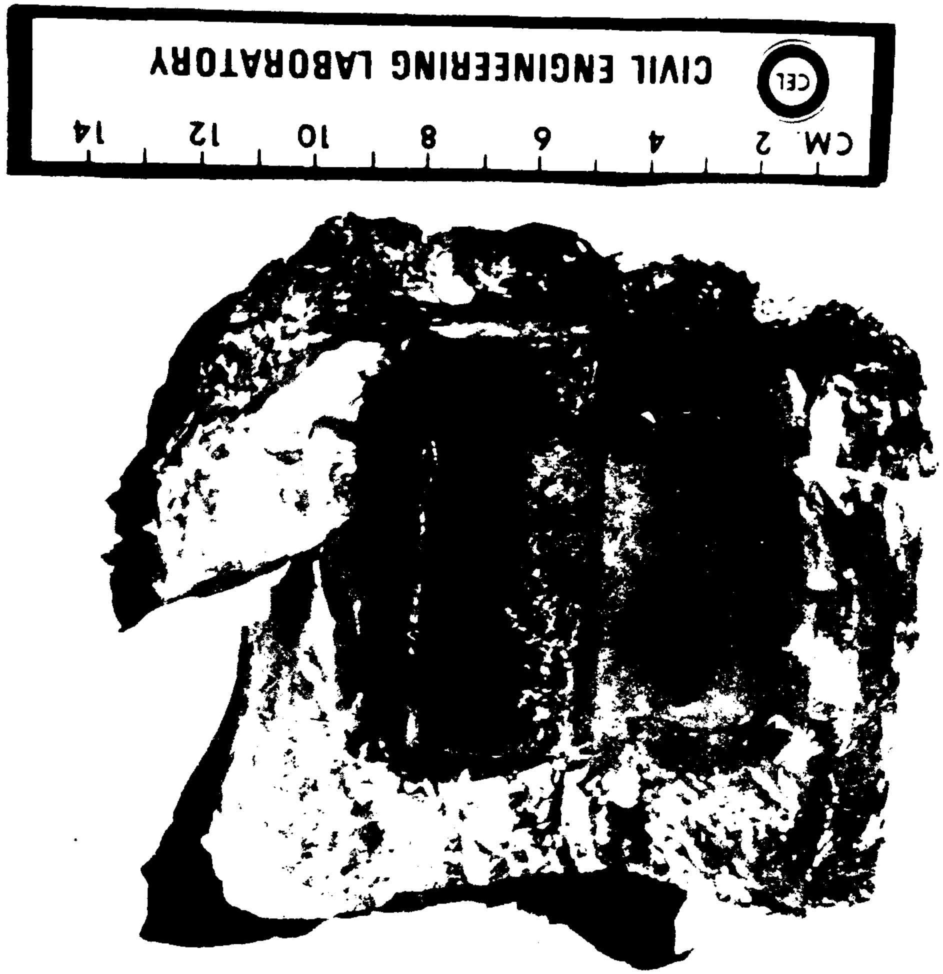


Figure 20. Partially wrapped lime-stabilized soil sample.

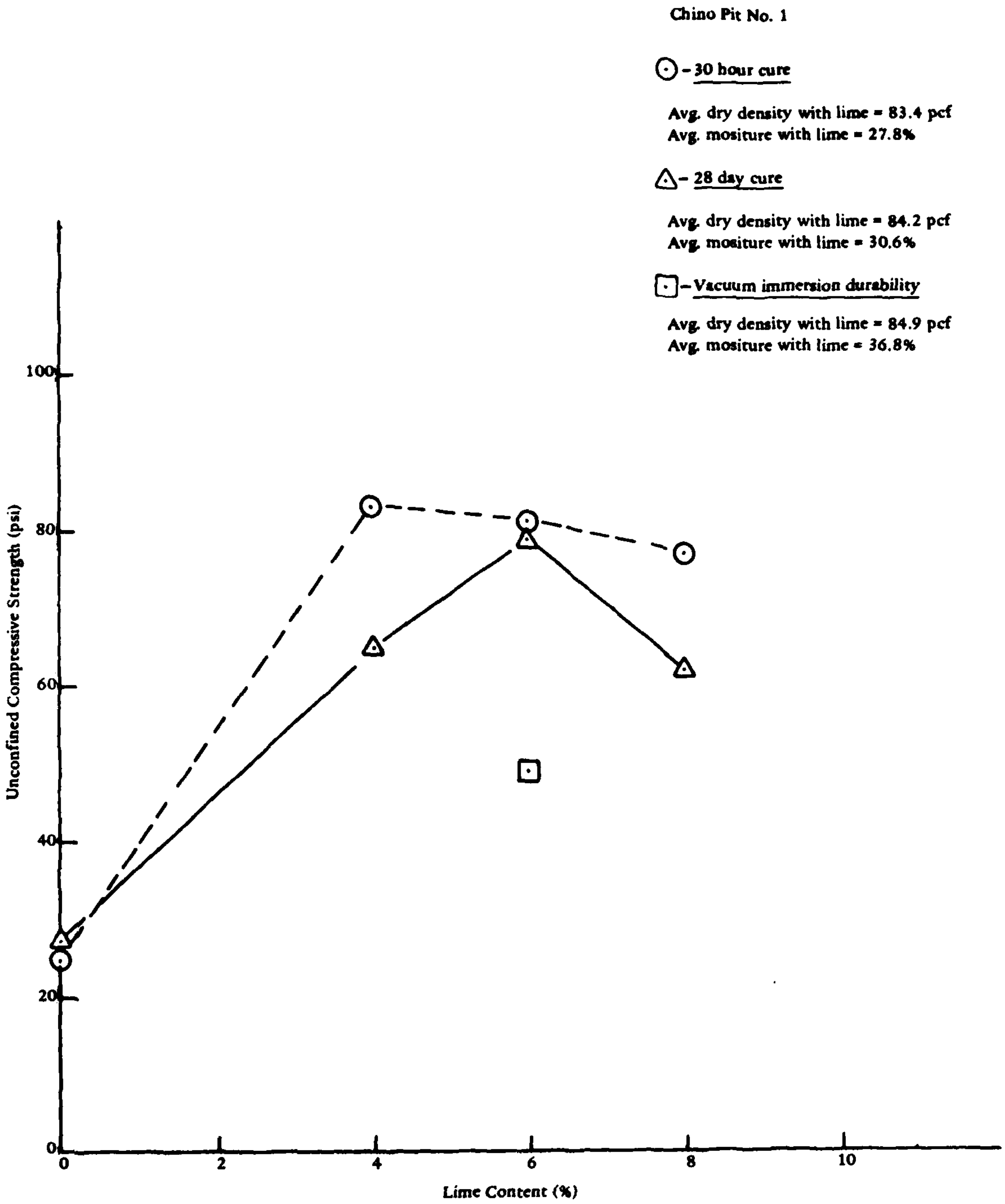


Figure 21. Unconfined compressive strengths, Chino Airport, Pit no. 1.

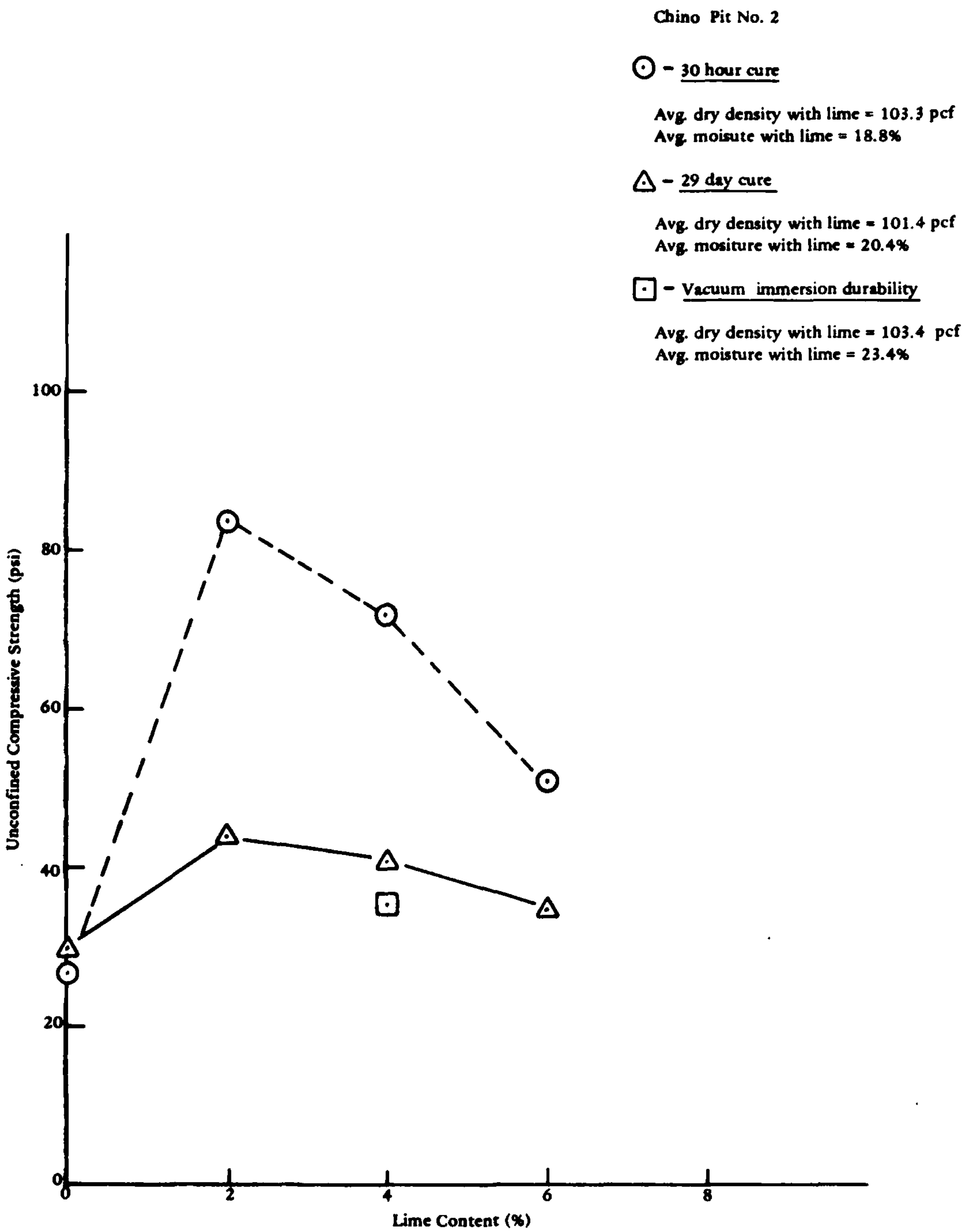


Figure 22. Unconfined compressive strengths, Chino Airport, Pit no. 2.

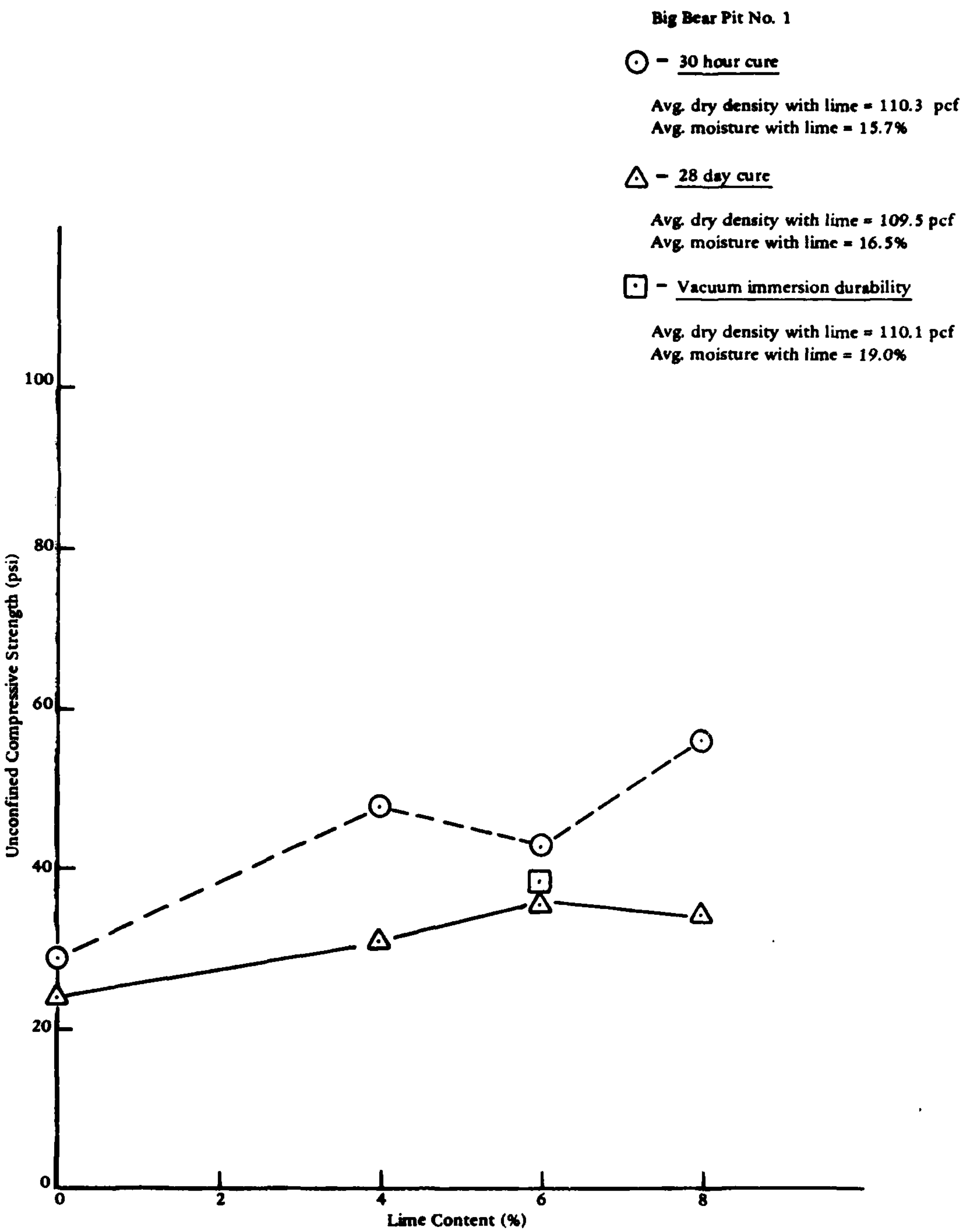


Figure 23. Unconfined compressive strengths, Big Bear Airport, Pit no. 1.

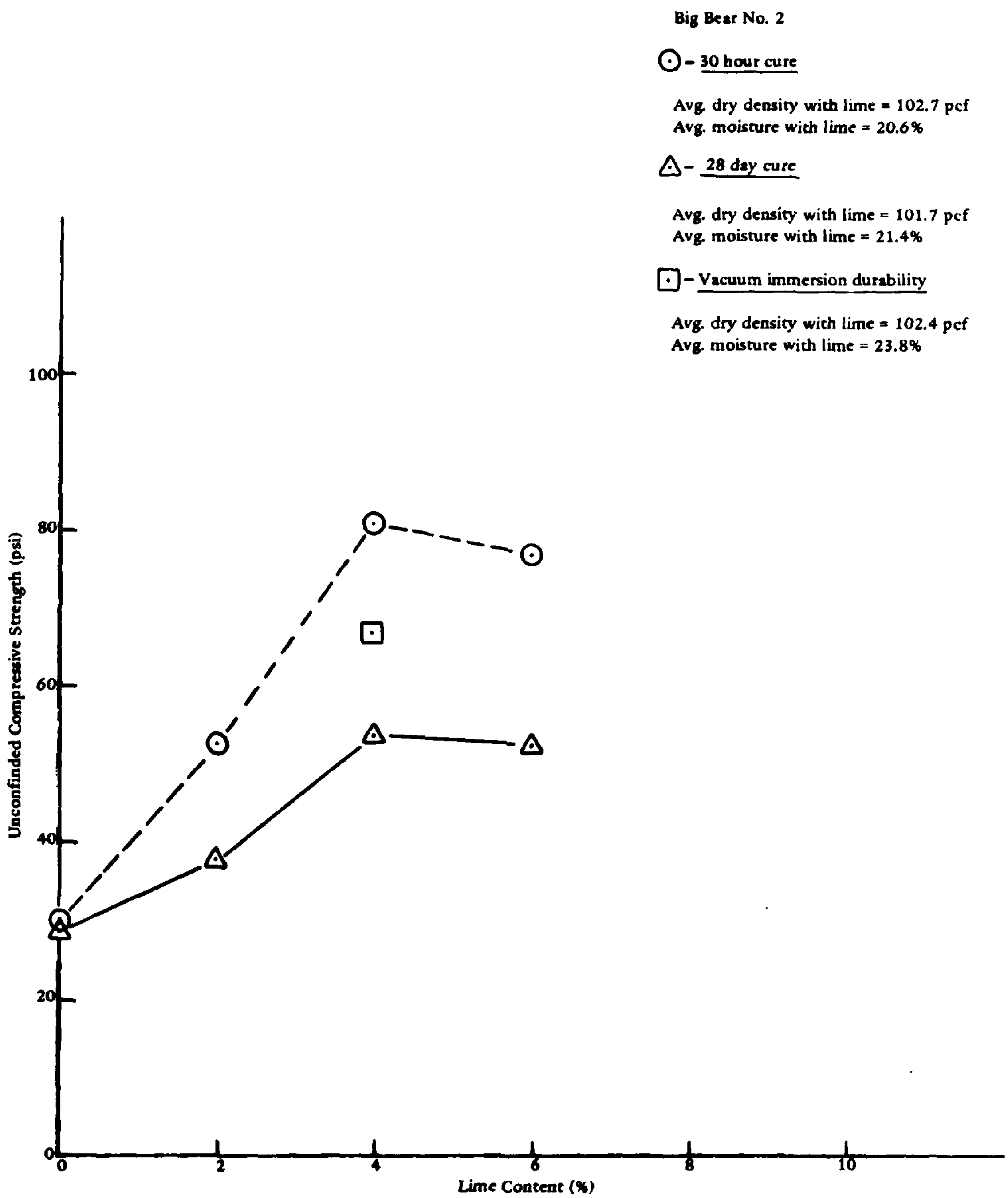


Figure 24. Unconfined compressive strengths, Big Bear Airport, Pit no. 2.

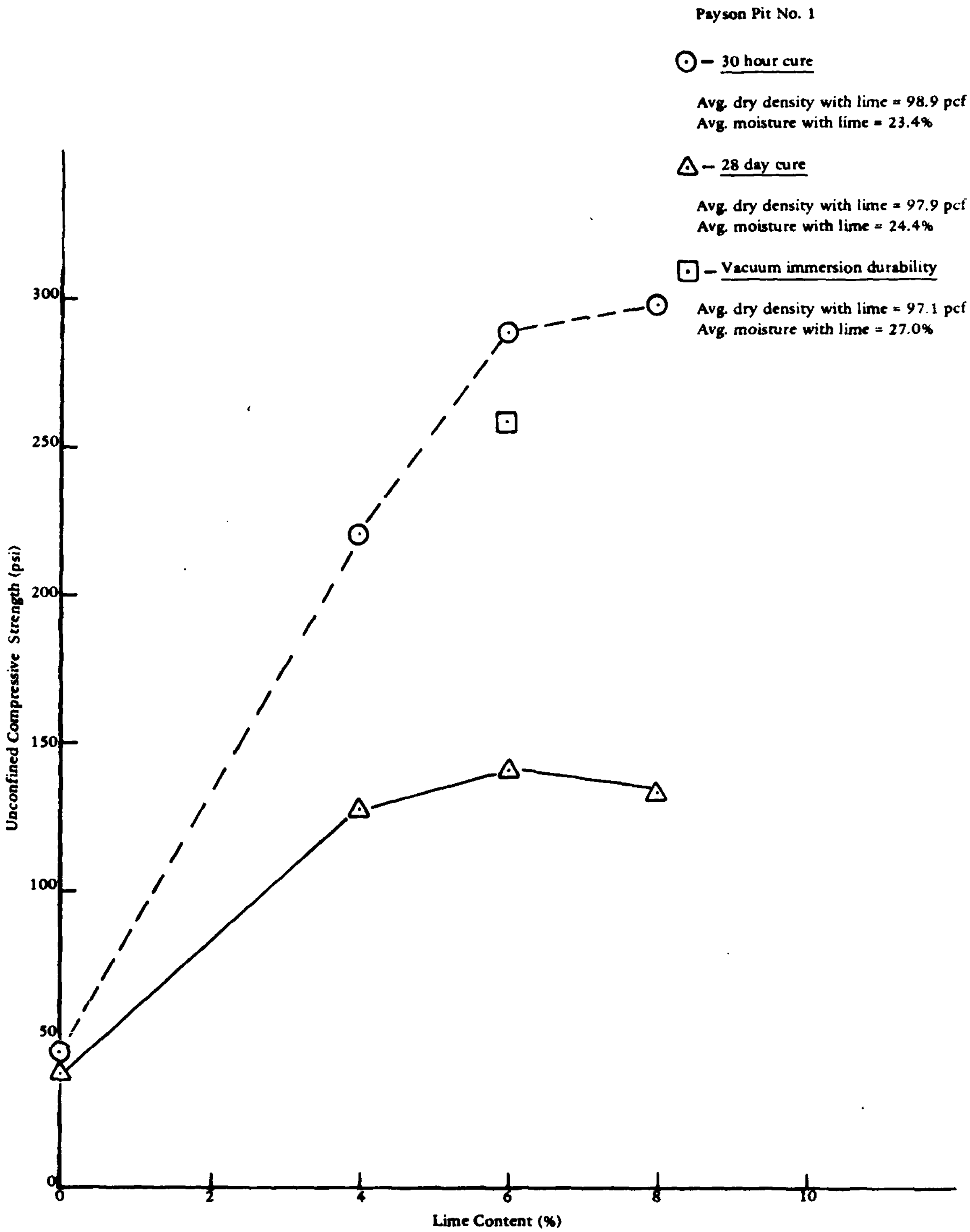


Figure 25. Unconfined compressive strengths, Payson Airport, Pit no. 1.

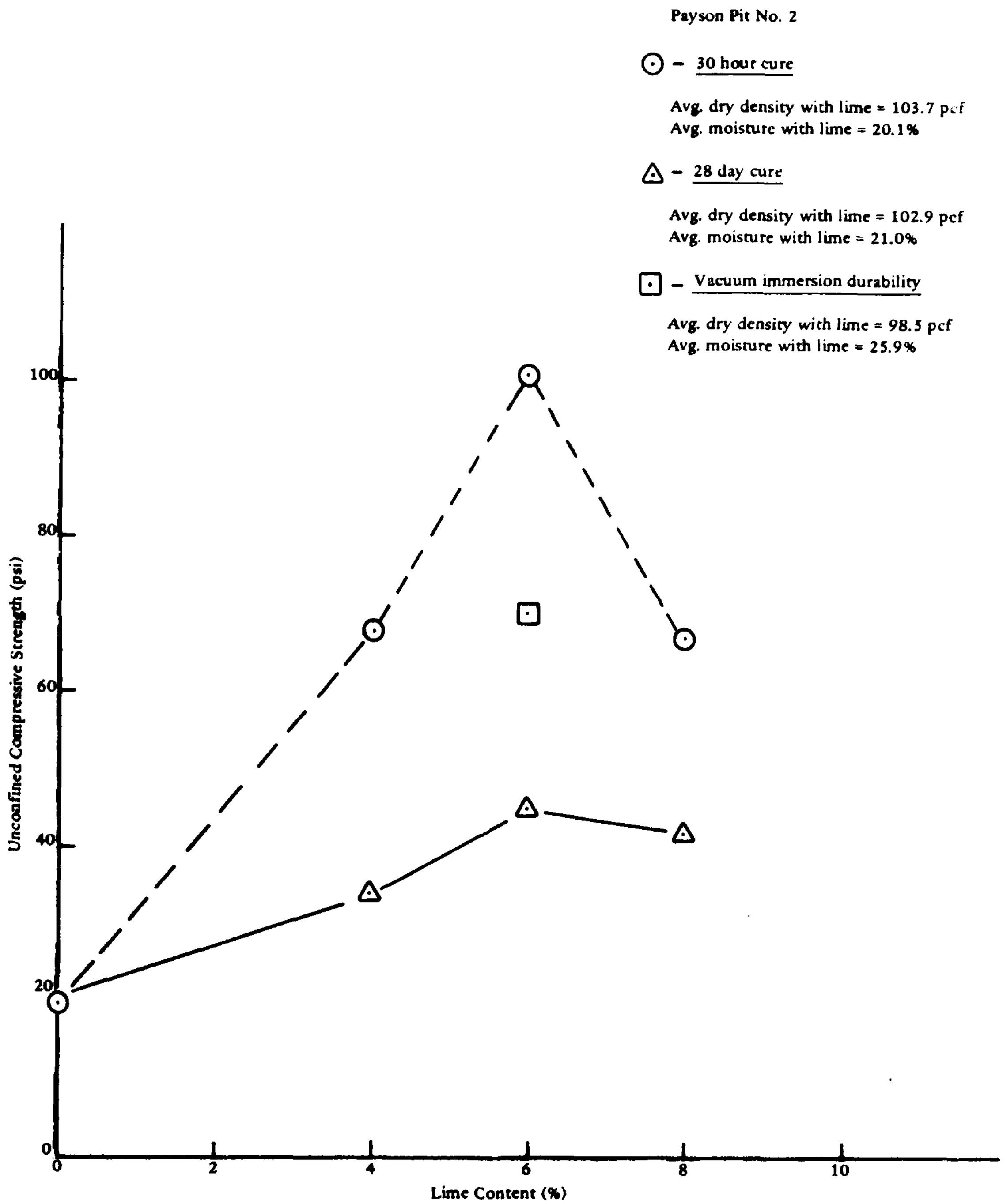


Figure 26. Unconfined compressive strengths, Payson Airport, Pit no. 2.

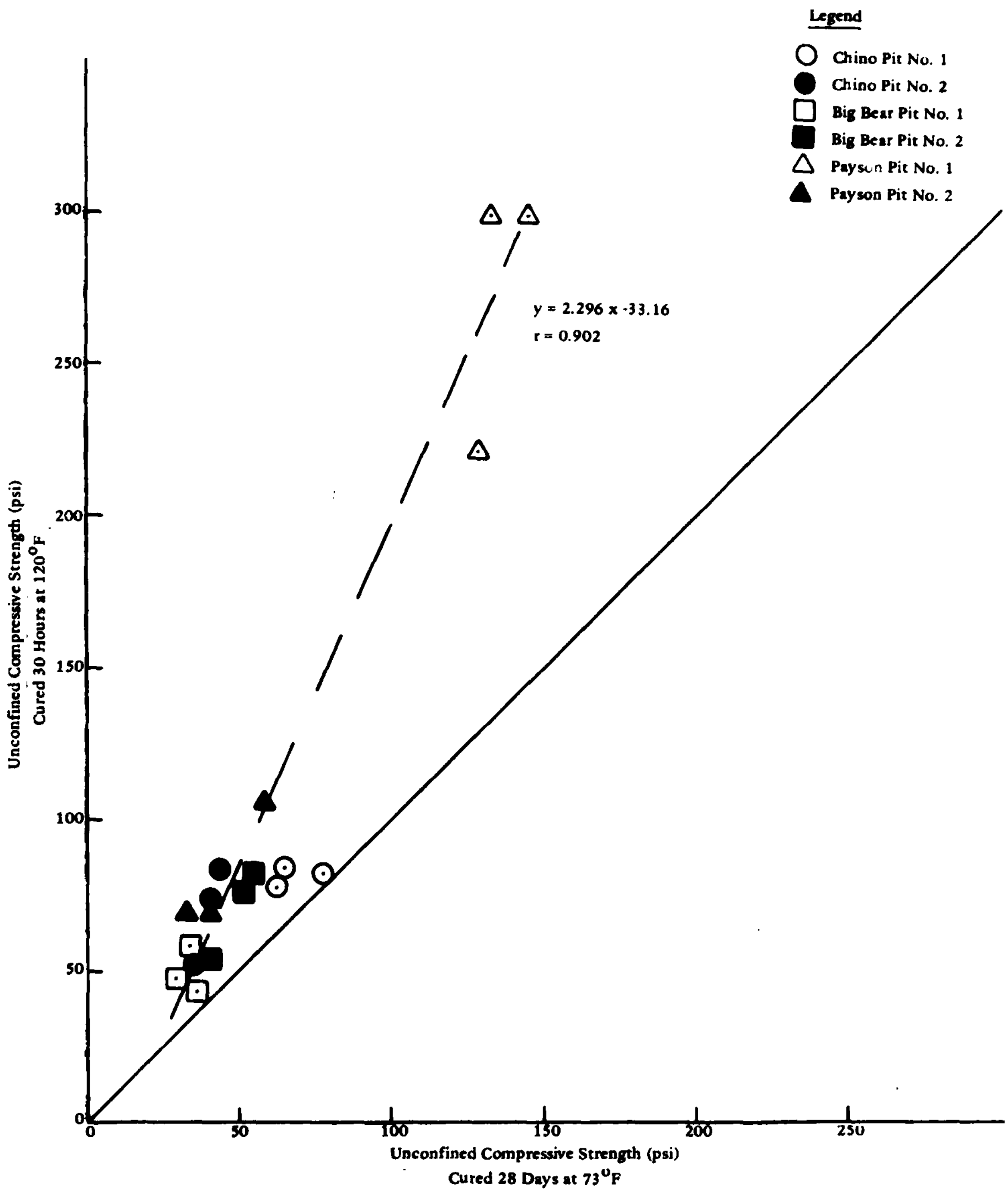


Figure 27. Correlation of accelerated and standard curing methods.

Figure 28. Lime-stabilized samples ready for vacuum saturation in triaxial cell.

Appendix A

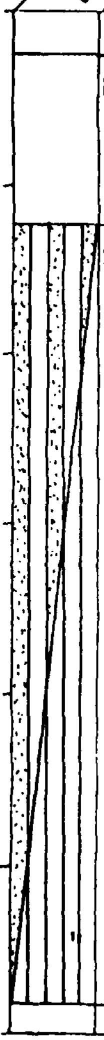
SOIL BORING LOGS

BORING NUMBER: 1

DATE: 8-16-78

LOCATION: Station 55+20
Taxiway 3-21
Chino Airport

DEPTH (ft)	BORING LOG	CLASSIFICATION SYMBOL	DESCRIPTION
0		AC	3.0 inches asphaltic concrete.
		LTB	12.0 inches lime treated base.
1.0		SM/ML	Grey-brown sandy silt, slight plasticity, loose and dry in place.
2.0			
3.0			
4.0			
5.0			
6.0			



BORING NUMBER: 2

DATE: 8-16-78

LOCATION: Station 45+20
Taxiway 3-21
Chino Airport

DEPTH (ft)	BORING LOG	CLASSIFICATION SYMBOL	DESCRIPTION
0		AC	3.5 inches asphaltic concrete.
		LTB	9.5 inches lime treated base.
1.0			
		ML	Grey-brown sandy silt, with traces of clay, slight plasticity, loose and dry in place.
2.0			
3.0			
4.0			
5.0			
6.0			

BORING NUMBER: 3

DATE: 8-17-78

LOCATION: Station 13+00
Taxiway 3-21
Chino Airport

DEPTH (ft)	BORING LOG	CLASSIFICATION SYMBOL	DESCRIPTION
0		AC	1.7 inches asphaltic concrete.
		LTB	13.0 inches lime treated base.
1.0		ML	Grey-brown sandy silt, slight plasticity, loose and dry in place.
2.0			
3.0			
4.0			
5.0			
6.0			

BORING NUMBER: 4

DATE: 8-17-78

LOCATION: Station 5+00
Taxiway 3-21
Chino Airport

DEPTH (ft)	BORING LOG	CLASSIFICATION SYMBOL	DESCRIPTION
0		AC	1.8 inches asphaltic concrete.
		LTB	12.0 inches lime treated base.
1.0			
		ML/CL	Grey-brown, clayey silt with traces of fine sand. Slightly plastic, dry and hard in place.
2.0			
3.0			
4.0			
5.0			
6.0			

BORING NUMBER: 5

DATE: 8-17-78

LOCATION: Station 5+00
Taxiway 8-26
Chino Airport

DEPTH (ft)	BORING LOG	CLASSIFICATION SYMBOL	DESCRIPTION
0		AC	1.5 inches asphaltic concrete.
		LTB	10.0 inches lime treated base.
1.0		ML	Grey-brown silt with traces of fine to medium sand, firm and moist in place.
2.0			
3.0			
4.0			
5.0			
6.0			

SUBGRADE SAMPLES

Subject: Chino Airport, Chino, California

Sample Location: Taxiway 3-21 Station 18+00 Right Side

Sample Location: Taxiway 3-21 Station 45+00 Left Side

BORING NUMBER: 1

DATE: 8-22-78

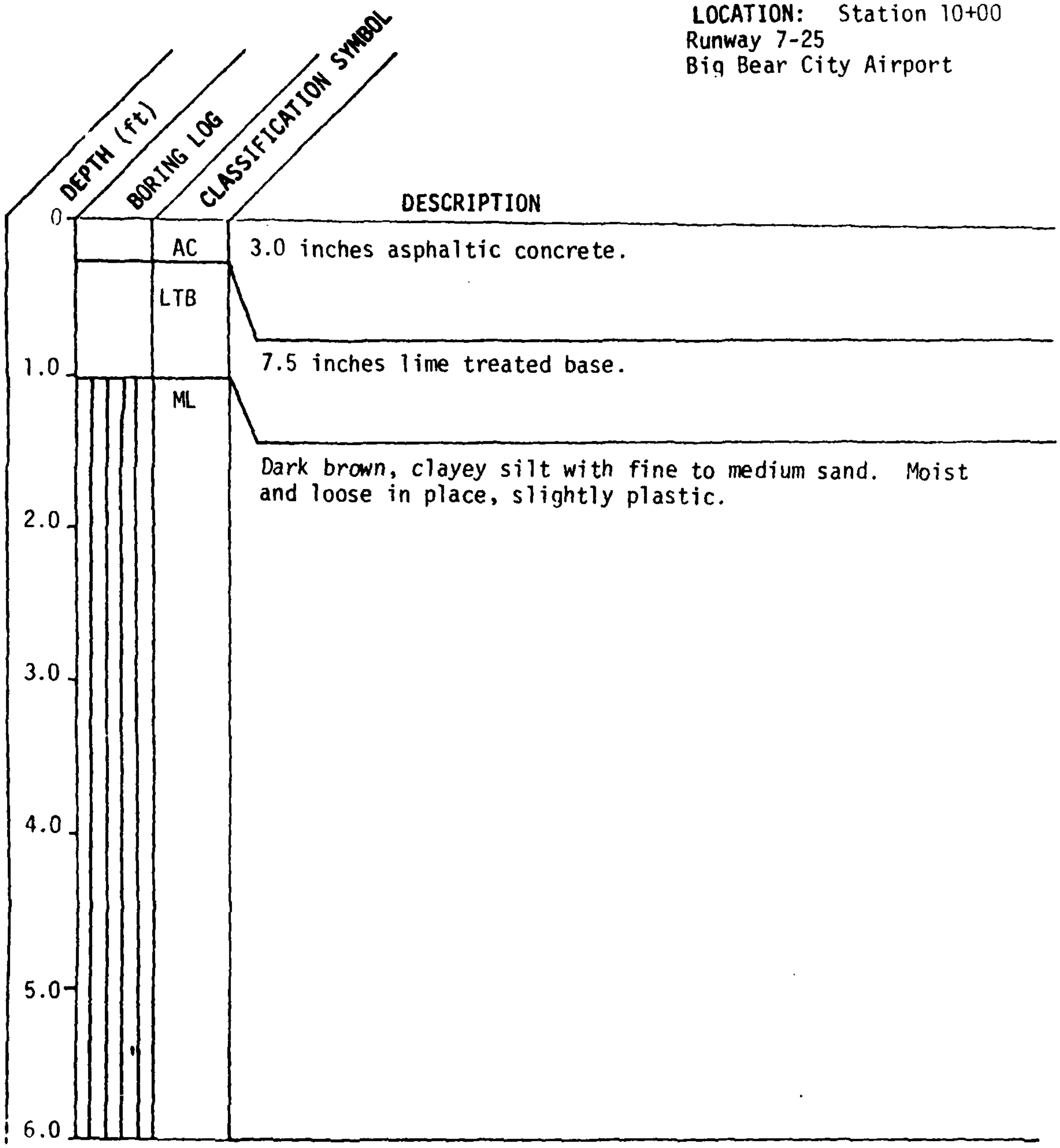
LOCATION: Station 6+00
18 feet south of CL
Runway 7-25
Big Bear City Airport

DEPTH (ft)	BORING LOG	CLASSIFICATION SYMBOL	DESCRIPTION
0		AC	2.7 inches asphaltic concrete.
		LTB	6.7 inches of lime treated base.
1.0		SM	Brown, very silty fine to medium sand with coarse sand. Moist and loose in place.
2.0			
3.0			
4.0			
5.0			
6.0			

BORING NUMBER: 2

DATE: 8-22-78

LOCATION: Station 10+00
Runway 7-25
Big Bear City Airport



BORING NUMBER: 3

DATE: 8-22-78

LOCATION: Station 25+00
Runway 7-25
Big Bear City Airport

DEPTH (ft)	BORING LOG	CLASSIFICATION SYMBOL	DESCRIPTION
0		AC	2.6 inches asphaltic concrete.
		LTB	11.5 inches lime treated base.
1.0			
		SM	Brown, very silty fine to medium sand with coarse sand. Moist and firm in place.
2.0			
3.0			
4.0			
5.0			
6.0			

BORING NUMBER: 4

DATE: 8-23-78

LOCATION: Station 40+00
Runway 7-25
Big Bear City Airport

DEPTH (ft)	BORING LOG	CLASSIFICATION SYMBOL	DESCRIPTION
0		AC	3.0 inches asphaltic concrete.
		LTB	10.5 inches lime treated base.
1.0		SM	Brown, very silty fine to medium sand with coarse sand. Moist and loose in place.
2.0			
3.0			
4.0			
5.0			
6.0			

BORING NUMBER: 5

DATE: 8-23-78

LOCATION: Station 50+00
Runway 7-25
Big Bear City Airport

DEPTH (ft)	BORING LOG	CLASSIFICATION SYMBOL	DESCRIPTION
0		AC	3.1 inches asphaltic concrete.
		LTB	10.1 inches lime treated base
1.0		SM	Brown, very silty fine to medium sand with coarse sand. Moist and loose in place.
2.0			
3.0			
4.0			
5.0			
6.0			

SUBGRADE SAMPLES

Subject: Big Bear City Airport, Big Bear City, California

Sample Location: Runway 7-25 Station 50+00 Right Side

Sample Location: Runway 7-25 Station 10+00 Right Side

BORING NUMBER: 1

DATE: 8-30-78

LOCATION: Station 49+00
Runway 6-24
Payson Airport

DEPTH (ft)	BORING LOG	CLASSIFICATION SYMBOL	DESCRIPTION
0		AC	2.5 inches asphaltic concrete.
		LTB	3.9 inches lime treated base.
1.0 – 5.0		CL	Reddish-brown, slightly silty clay with fine to medium sand. Plastic and expansive in nature. Soft to stiff with depth. Moist in place.
6.0			

BORING NUMBER: 2

DATE: 8-30-78

LOCATION: Station 38+65
Runway 6-24
Payson Airport

DEPTH (ft)	BORING LOG	CLASSIFICATION SYMBOL	DESCRIPTION
0		AC	1.6 inch asphaltic concrete.
		LTB	6.0 inches lime treated base.
1.0 – 6.0		CL	Reddish-brown, slightly silty clay with fine to medium sand. Plastic and expansive in nature. Stiff and moist in place.

BORING NUMBER: 3

DATE: 8-30-78

LOCATION: Station 29+00
Runway 6-24
Payson Airport

DEPTH (ft)	BORING LOG	CLASSIFICATION SYMBOL	DESCRIPTION
0		AC	1.6 inches asphaltic concrete.
		LTB	12.0 inches lime treated base.
1.0			
		SC	Decomposed granite - Reddish-brown slightly silty, very clayey fine to coarse sand with fine gravel. Slightly plastic, potentially expansive in nature. Moist and soft in place.
2.0			
3.0			
4.0			
5.0			
6.0			

BORING NUMBER: 4

DATE: 8-30-78

LOCATION: Station 19+00
Runway 6-24
Payson Airport

DEPTH (ft)	BORING LOG	CLASSIFICATION SYMBOL	DESCRIPTION
0		AC	2.2 inches asphaltic concrete.
		LTB	12.0 inches lime treated base.
1.0			
		CL	Reddish-brown, slightly silty clay with fine to medium sand. Plastic and expansive in nature. Stiff and moist in place.
2.0			
3.0			
4.0			
5.0			
6.0			

BORING NUMBER: 5

DATE: 8-30-78

LOCATION: Station 9+00
Runway 6-24
Payson Airport

DEPTH (ft)	BORING LOG	CLASSIFICATION SYMBOL	DESCRIPTION
0			2.2 inches asphaltic concrete.
			12.1 inches lime treated base.
1.0			Red-brown silty clay with fine to medium sand. Plastic and expansive in nature. Moist and stiff in place.
2.0			
3.0			
4.0			
5.0			
6.0			

SUBGRADE SAMPLES

Subject: Payson Airport, Payson, Arizona

Sample Location: Runway 6-24 Station 29+00 Right Side

Sample Location: Runway 6-24 Station 19+00 Right Side

Appendix B

SURFACE DEFLECTION MEASUREMENTS

CHINO AIRPORT

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca. Date Tested 8-17-78

Location Taxiway 3-21

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
0+15 100'-Left	97°	29	
0+15 50'-Left		35	
0+50		7	
1+00		22	
1+50		30	
2+00		24	
2+50		2	
3+00		12	
3+50		28	Transverse cracking
4+00		40	Alligator cracks
4+50		16	Slight transverse cracking
5+00		37	Longitudinal cracking
5+50		43	Slight alligator cracks
6+00		24	Slight alligator cracks
6+50		8	
7+00		34	
7+50		53	Slight alligator cracks
8+00		42	
8+50		41	
9+00		15	Alligator cracks
9+50		29	

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca. Date Tested 8-17-78

Location Taxiway 3-21

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
10+00		15	
10+50		18	Transverse cracking
11+00		18	
11+50		3	
12+00		2	
12+50		2	
13+00		6	
13+50		6	
14+00		23	
14+50		23	
15+00		21	
15+50		5	
16+00		6	
16+50		4	
17+00		2	
17+50		11	
18+00		26	
18+50		34	
19+00		30	Alligator cracks
19+50		8	

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca. Date Tested 8-17-78

Location Taxiway 3-21

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
20+00		40	
20+50		10	
21+00		27	
21+50		41	Slight cracking
22+00		34	Slight cracking
22+50		14	Slight cracking
23+00		8	
23+50		1	
24+00	102°	9	

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca. Date Tested 8-16-78

Location Taxiway 3-21

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
30+00	96°	11	Longitudinal cracks
30+50		7	
31+00		15	
31+50		15	Longitudinal cracking
32+00		8	
32+50		11	Longitudinal cracking
33+00		8	
33+50		6	
34+00		9	
34+50		10	
35+00		20	
35+50		10	
36+00		11	Longitudinal cracks
36+50		15	
37+00		10	
37+50		5	
38+00		7	
38+50		10	
39+00		8	
39+50		10	
40+00		9	

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca. Date Tested 8-16-78

Location Taxiway 3-21

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
40+50		7	
41+00		10	
41+50		8	
42+00		3	
42+50		9	
43+00		3	
43+50		7	
44+00		5	Slight transverse cracks along edge of pavement
44+50		2	Slight transverse cracks along edge of pavement
45+00		2	
45+50		5	
46+00		2	Slight longitudinal cracks
46+50		4	Slight transverse cracks
47+00		4	Slight transverse cracks
47+50		2	
48+00		14	
48+50		6	
49+00		8	
49+50		2	
50+00		2	

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca. Date Tested 8-16-78

Location Taxiway 3-21

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
50+50		8	Longitudinal cracks
51+00		6	
51+50		2	Longitudinal cracks
52+00		6	
52+50		9	
53+00		12	
53+50		2	
54+00		13	Longitudinal cracks
54+50		11	
55+00		7	
55+50		7	
56+00		14	
56+50		8	Longitudinal cracks
57+00		14	Longitudinal cracks along edge of pavement
57+50		8	Longitudinal cracks along edge of pavement
58+00		10	
58+50		2	
59+00		4	
59+50		6	
60+00		8	

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca.   Date Tested 8-16-78

Location Taxiway 3-21

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
60+10 25' Left		8	
60+10 75' Left		10	
60+10 125' Left		6	

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca. Date Tested 8-17-78

Location Taxiway 3-21

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
0+35 100' Left	102°	74	Heavy cracking
0+35 50' Left		30	
0+50		60	
1+00		16	
1+50		10	
2+00		16	
2+50		18	Longitudinal cracking
3+00		44	Longitudinal cracking
3+50		16	
4+00		18	Longitudinal cracks along edge and depression in pavement
4+50		30	
5+00		28	Alligator cracks
5+50		60	Longitudinal cracks
6+00		40	Longitudinal cracks
6+50		13	
7+00		11	
7+50		9	
8+00		30	Longitudinal cracks
8+50		18	Longitudinal cracks
9+00		40	Longitudinal cracks

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca. Date Tested 8-17-78

Location ,axiway 3-21

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
9+50		14	
10+00		19	Longitudinal cracks
10+50		9	Alligator cracking
11+00		9	
11+50		4	
12+00		5	
12+50		5	
13+00		20	
13+50		14	
14+00		9	
14+50		25	
15+00		1	
15+50		13	
16+00		10	
16+50		7	
17+00		8	
17+50		20	
18+00		11	
18+50	102°	10	
19+00		12	
19+50		15	

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca. Date Tested 8-17-78

Location Taxiway 3-21

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
20+00		1	
20+50		20	
21+00		6	
21+50		10	
22+00		2	
22+50		4	
23+00		24	
23+50		19	
24+00		8	

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca. Date Tested 8-16-78

Location Taxiway 3-21

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
30+00		14	
30+50		8	
31+00		0	
31+50		0	
32+00		4	
32+50		6	
33+00		4	
33+50		7	
34+00		10	
34+50		10	Transverse cracking
35+00		0	
35+50		2	
36+00		10	Transverse cracks
36+50		5	Transverse cracks
37+00		7	
37+50		9	
38+00		11	
38+50		10	
39+00		9	
39+50		8	
40+00		6	

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca. Date Tested 8-16-78

Location Taxiway 3-21

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
40+50	103°	2	
41+00		5	
41+50		13	Transverse cracking
42+00		2	Transverse cracking
42+50		2	Transverse cracking
43+00		7	
43+50		13	
44+00		8	
44+50		10	
45+00		14	Longitudinal cracking
45+50		10	
46+00		10	
46+50		13	
47+00		12	
47+50		5	
48+00		13	
48+50		2	
49+00		2	
49+50		7	
50+00		13	
50+50		8	Longitudinal cracks

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca. Date Tested 8-16-78

Location Taxiway 3-21

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
51+00		13	
51+50		8	Longitudinal cracks
52+00		10	
52+50		10	
53+00		13	
53+50		7	
54+00		12	Longitudinal cracks
54+50		7	
55+00		10	
55+50		5	
56+00		12	
56+50		11	
57+00		12	
57+50		15	
58+00		12	
58+50		12	
59+00		12	
59+50		9	
60+00		12	
60+10 25' Left		17	
60+10 75' Left		15	
60+10 125' Left		18	

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca. Date Tested 8-17-78

Location Taxiway 8-26

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
0+00	112°		
0+50		26	
1+00		30	
1+50		30	
2+00		60	
2+50		40	
3+00		20	
3+50		52	
4+00		30	
4+50		9	
5+00		40	
5+50		50	
6+00		60	
6+50		20	
7+00		28	
7+50		7	
8+00		30	
15+00		26	Longitudinal and transverse cracking
15+50		32	Longitudinal and transverse cracking
16+00		46	Longitudinal and transverse cracking
16+50		16	

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca. Date Tested 8-17-78

Location Taxiway 8-26

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
17+00		9	
17+50		36	
18+00		44	
18+50		30	
19+00		40	
19+50		30	
20+00		13	Longitudinal crack
20+50		17	
21+00		20	
21+50		15	
22+00		24	
22+50		32	
23+00		23	
23+50		26	
24+00		16	
24+50		26	
25+00		42	

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca. Date Tested 8-17-78

Location Taxiway 8-26

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
0+50	112°	6	Longitudinal cracking
1+00		80	Longitudinal cracking with depression
1+50		50	Longitudinal cracking with depression
2+00		24	
2+50		40	
3+00		28	
3+50		20	
4+00		10	
4+50		80	
5+00		50	
5+50		20	
6+00		9	
6+50		20	
7+00		22	
7+50		22	
8+00		5	
15+50		40	Longitudinal and transverse cracking
16+00		40	Longitudinal and transverse cracking
16+50		60	Longitudinal and transverse cracking
17+00		27	Longitudinal and transverse cracking

BENKELMAN BEAM

Subject Chino Airport, Chino, Ca.   Date Tested 8-17-78

Location Taxiway 8-26

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
17+50		36	
18+00		24	
18+50		46	
19+00		54	
19+50		38	
20+00		26	
20+50		1	
21+00		8	
21+50		40	
22+00		44	
22+50		20	
23+00		13	
23+50		21	
24+00		14	
24+50		20	
25+00		43	

BIG BEAR CITY AIRPORT

BENKELMAN BEAM

Subject Big Bear City Airport, Big Bear City, Ca. Date Tested 8-22-78

Location Runway 7-25

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
5+00	85°	20	Slight longitudinal cracking
5+50		40	Longitudinal and transverse cracking with depressions in pavement
6+00		140	Longitudinal and transverse cracking with depressions in pavement
6+50		40	Open longitudinal cracking
7+00		60	Longitudinal cracking
7+50		100	Longitudinal cracking
8+00		60	Longitudinal cracking
8+50		24	Slight longitudinal cracking
9+00		20	
9+50		20	
10+00		24	Open longitudinal cracks
10+50		10	Longitudinal cracks along edge of pavement
11+00		30	Longitudinal cracks along edge of pavement
11+50		26	Longitudinal cracks along edge of pavement and deep depressions
12+00		60	Longitudinal cracks along edge of pavement and deep depressions
12+50		20	Slight transverse cracking
13+00		20	
13+50		20	

AD-A102 196 CIVIL ENGINEERING LAB (NAVY) PORT HUENEME CA F/G 13/2
LIME-STABILIZED NATIVE SOIL AS A BASE COURSE FOR LIGHT AIRCRAFT--ETC(U)
APR 81 R B BROWNIE DOT-FA78WAI-834
UNCLASSIFIED FAA/RD-80/112 NL

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BENKELMAN BEAM

Subject Big Bear City Airport, Big Bear City, Ca. Date Tested 8-22-78

Location Runway 7-25

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
14+00		16	Longitudinal cracks along edge of pavement
14+50		20	Slight longitudinal cracks along edge of pavement
15+00		6	
15+50		6	
16+00		4	
16+50		3	
17+00		5	
17+50		3	Longitudinal cracks along edge of pavement
18+00		2	
18+50		8	Transverse cracking
19+00		7	
19+50		20	
20+00		10	Longitudinal cracking
20+50		3	
21+00		10	
21+50		3	
22+00		6	
22+50		3	
23+00		2	
23+50		21	

BENKELMAN BEAM

Subject Big Bear City Airport, Big Bear City, Ca. Date Tested 8-22-78

Location Runway 7-25

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
24+00		21	
24+50		8	
25+00		13	
25+50		17	
26+00		18	Transverse cracking
26+50		17	Longitudinal and transverse cracking
27+00		15	
27+50		17	Transverse cracking
28+00		18	
28+50		11	
29+00		9	
29+50		10	
30+00		1	
30+50		16	
31+00		3	
31+50		4	
32+00		10	
32+50		7	
33+00		17	
33+50		9	

BENKELMAN BEAM

Subject Big Bear City Airport, Big Bear City, Ca. Date Tested 8-22-78

Location Runway 7-25

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
34+00		6	
34+50		8	
35+00		7	
35+50		2	
36+00		8	
36+50		6	
37+00		2	
37+50		1	
38+00	95°	5	

BENKELMAN BEAM

Subject Big Bear City Airport, Big Bear City, Ca. Date Tested 8-23-78

Location Runway 7-25

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
38+50		4	
39+00		2	
39+50		10	
40+00		10	
40+50		8	
41+00		10	
41+50		10	
42+00		12	
42+50		8	
43+00		10	
43+50		8	
44+00		6	
44+50	101°	8	
45+00		4	
45+50		12	
46+00		10	
46+50		10	
47+00		10	
47+50		12	
48+00		8	
48+50		12	

BENKELMAN BEAM

Subject Big Bear City Airport, Big Bear City, Ca. Date Tested 8-23-78

Location Runway 7-25

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
49+00		10	
49+50		10	
50+00		14	
50+50		10	
51+00		14	
51+50		16	
52+00		12	
52+50		16	
53+00		24	
53+50		14	Slight longitudinal cracks
54+00		18	
54+50		22	
55+00	106°	16	

BENKELMAN BEAM

Subject Big Bear City Airport, Big Bear City, Ca. Date Tested 8-22-78

Location Runway 7-25

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
5+00	104°	10	
5+10		10	
6+00		7	
6+50		30	Longitudinal cracks with depressions
7+00		7	Longitudinal cracks with depressions
7+50		8	Longitudinal cracks with depressions
8+00		60	Longitudinal cracks with depressions
8+50		80	Longitudinal cracks with depressions
9+00		60	Longitudinal cracks with depressions
9+50		2	Longitudinal cracking
10+00		10	
10+50		7	Longitudinal cracking
11+00		10	
11+50		4	
12+00		9	
12+50		20	
13+00		20	
13+50		8	
14+00		7	
14+50		9	
15+00		20	

BENKELMAN BEAM

Subject Big Bear City Airport, Big Bear City, Ca. Date Tested 8-22-78

Location Runway 7-25

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
15+50		1	
16+00		2	
16+50		2	
17+00		1	
17+50		5	
18+00		5	Transverse cracking
18+50		20	
19+00		10	
19+50		3	
20+00	105°	10	
20+50		14	
21+00		10	
21+50		2	
22+00		1	
22+50		3	
23+00		20	
23+50		14	
24+00		20	
24+50		40	
25+00		10	

BENKELMAN BEAM

Subject Big Bear City Airport, Big Bear City, Ca. Date Tested 8-22-78

Location Runway 7-25

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
25+50		30	
26+00		18	Longitudinal cracks
26+50		40	
27+00		20	
27+50		30	Longitudinal cracks
28+00		20	Longitudinal cracks
28+50		16	
29+00		20	
29+50		20	
30+00		20	
30+50		20	
31+00		20	
31+50		20	
32+00		6	
32+50		18	
33+00		16	
33+50		8	
34+00		10	
34+50		7	
35+00		3	
35+50		10	

BENKELMAN BEAM

Subject Big Bear City Airport, Big Bear City, Ca. Date Tested 8-22-78

Location Runway 7-25

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
36+00		10	
36+50		10	
37+00		10	
37+50		3	
38+00	95°	2	

BENKELMAN BEAM

Subject Big Bear City Airport, Big Bear City, Ca. Date Tested 8-23-78

Location Runway 7-25

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
38+50	89°	4	
39+00		4	
39+50		10	
40+00		12	
40+50		14	
41+00		14	
41+50		8	
42+00		10	
42+50		12	
43+00		10	
43+50		8	
44+00		14	
44+50		14	
45+00		12	
45+50		12	
46+00		8	
46+50		18	
47+00		10	
47+50		8	
48+00		4	
48+50		14	

BENKELMAN BEAM

Subject Big Bear City Airport, Big Bear City, Ca. Date Tested 8-23-78

Location Runway 7-25

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
49+00		6	
49+50		10	
50+00		18	
50+50		14	
51+00		16	
51+50		18	
52+00		12	
52+50		14	
53+00		22	
53+50		4	
54+00		12	
54+50	103°	8	
55+00		6	

BENKELMAN BEAM

Subject Big Bear City Airport, Big Bear City, Ca. Date Tested 8-23-78

Location Taxiway 7-25

Station	Temperature Fahrenheit	Deflection 0.001"	Remarks
20+50			
21+00		12	
21+50		18	
22+00		6	
22+50		14	
23+00		8	
23+50		12	
24+00		16	
24+50		16	
25+00		12	
25+50		40	
26+00		20	
26+50		46	
27+00		10	
27+50		16	
28+00		18	
28+50		12	
29+00		8	
29+50		12	
30+00		16	

BENKELMAN BEAM

Subject Big Bear City Airport, Big Bear City, Ca. Date Tested 8-23-78

Location Taxiway 7-25

Station	Temperature Fahrenheit	Deflection 0.001"	Remarks
30+50		16	
31+00		18	
31+50		10	
32+00		14	
32+50		10	
33+00		10	
33+50		12	
34+00		18	
34+50		16	
35+00		6	
35+50		4	
36+00		12	
36+50		14	
37+00		10	
37+50		16	
38+00		13	
38+50		6	
39+00		6	
39+50		12	
40+00		12	
40+50		10	

PAYSON AIRPORT

BENKELMAN BEAM

Subject Payson Airport, Payson, Arizona   Date Tested 8-30-78

Location Runway 6-24

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
4+50	100°	8	Constant Longitudinal Cracks Throughout With Transverse Cracking
5+00		8	
5+50		10	
6+00		10	
6+50		8	
7+00		12	
7+50		10	
8+00		20	
8+50		20	
9+00		12	
9+50		18	
10+00		30	
10+50		12	
11+00		10	
11+50		12	
12+00		13	
12+50		10	
13+00		14	
13+50		24	
14+00		14	
14+50		10	

BENKELMAN BEAM

Subject Payson Airport, Payson, Arizona Date Tested 8-30-78

Location Runway 6-24

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
15+00		20	Constant Longitudinal Cracks Throughout With Transverse Cracking
15+50		14	
16+00		18	
16+50		17	
17+00		8	
17+50		4	
18+00		10	
18+50		14	
19+00		15	
19+50		20	
20+00		10	
20+50		12	
21+00		10	
21+50		14	
22+00		19	
22+50		18	
23+00		21	
23+50		33	
24+00		24	
24+50		8	
25+00		20	

BENKELMAN BEAM

Subject Payson Airport, Payson, Arizona Date Tested 8-30-78

Location Runway 6-24

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
25+50	112°	6	Constant Longitudinal Cracks Throughout With Transverse Cracking
26+00		11	
26+50		6	
27+00		20	
27+50		20	
28+00		20	
28+50		21	
29+00		20	
29+50		26	
30+00		26	
30+50		14	
31+00		12	
31+50		8	
32+00		10	
32+50		20	
33+00		30	
33+50		22	
34+00		8	
34+50		22	
35+00		34	
35+50		18	

BENKELMAN BEAM

Subject Payson Airport, Payson, Arizona Date Tested 8-30-78

Location Runway 6-24

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
36+00		50	Constant Longitudinal Cracks Throughout With Transverse Cracking
36+50		20	
37+00		20	
37+50		20	
38+00		30	
38+50		40	
39+00		50	
39+50		40	
40+00		30	
40+50		18	
41+00		30	
41+50		18	
42+00		20	
42+50		20	
43+00		20	
43+50		20	
44+00	119°	18	
44+50		20	
45+00		20	
45+50		40	

BENKELMAN BEAM

Subject Payson Airport, Payson, Arizona Date Tested 8-30-78

Location Runway 6-24

Station 10 ft.-Right	Temperature Fahrenheit	Deflection 0.001"	Remarks
46+00		20	Constant Longitudinal Cracks Throughout With Transverse Cracking
46+50		40	
47+00	109°	50	
47+50		70	
48+00		60	
48+50		20	
49+00		20	
49+50		16	
50+00		10	
50+50		13	
51+00		22	
51+50		20	
52+00		24	
52+50		24	

BENKELMAN BEAM

Subject Payson Airport, Payson, Arizona Date Tested 8-30-78

Location Runway 6-24

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
4+50		14	Constant Longitudinal Cracks Throughout With Transverse Cracking
5+00		10	
5+50		10	
6+00		8	
6+50		10	
7+00		8	
7+50		6	
8+00		20	
8+50		18	
9+00		28	
9+50		24	
10+00		10	
10+50		20	
11+00		18	
11+50		20	
12+00	97°	10	
12+50		6	
13+00		8	
13+50		9	
14+00		10	
14+50		20	

BENKELMAN BEAM

Subject Payson Airport, Payson, Arizona Date Tested 8-30-78

Location Runway 6-24

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
15+00		10	Constant Longitudinal Cracks Throughout With Transverse Cracking
15+50		8	
16+00		8	
16+50		20	
17+00		10	
17+50		5	
18+00		20	
18+50		5	
19+00		10	
19+50		20	
20+00		6	
20+50		10	
21+00		10	
21+50		14	
22+00		10	
22+50		10	
23+00		6	
23+50	105°	10	
24+00		8	
24+50		6	
25+00		20	

BENKELMAN BEAM

Subject Payson Airport, Payson, Arizona Date Tested 8-30-78

Location Runway 6-24

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
25+50		10	Constant Longitudinal Cracks Throughout With Transverse Cracking
26+00		30	
26+50		10	
27+00		20	
27+50		11	
28+00		16	
28+50		24	
29+00		60	
29+50		10	
30+00		20	
30+50		10	
31+00		24	
31+50		30	
32+00		20	
32+50		16	
33+00		25	
33+50		10	
34+00		10	
34+50		34	
35+00		28	
35+50		32	

BENKELMAN BEAM

Subject Payson Airport, Payson, Arizona Date Tested 8-30-78

Location Runway 6-24

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
36+00		14	Constant Longitudinal Carcks Throughout With Transverse Cracking
36+50		21	
37+00		30	
37+50		18	
38+00		31	
38+50		13	
39+00		18	
39+50		29	
40+00		52	
40+50		20	
41+00		14	
41+50		42	
42+00		36	
42+50		6	
43+00		10	
43+50		30	
44+00		40	
44+50		22	
45+00		16	
45+50		30	
46+00		30	

BENKELMAN BEAM

Subject Payson Airport, Payson, Arizona　　　　Date Tested 8-30-78

Location Runway 6-24

Station 10 ft.-Left	Temperature Fahrenheit	Deflection 0.001"	Remarks
46+50		30	Constant Longitudinal Cracks Throughout With Transverse Cracking
47+00		30	
47+50		20	
48+00		30	
48+50		6	
49+00		6	
49+50		10	
50+00		14	
50+50		10	
51+00		30	
51+50		6	
52+00		10	
52+50	114°	20	

BENKELMAN BEAM

Subject Payson Airport, Payson, Arizona — Date Tested 8-30-78

Location Runway 6-24 Warm Up Ramps

Station	Temperature Fahrenheit	Deflection 0.001"	Remarks
52+50 25' Right		20	
52+50 50' Right		40	
52+50 75' Right		40	
52+75 25' Right		30	
52+75 50' Right		10	
52+75 75' Right		20	
4+25 25' Right		10	
4+25 50' Right		12	
4+25 75' Right		12	
4+50 25' Right		20	
4+50 50' Right		14	
4+50 75' Right		12	

BENKELMAN BEAM

Subject Payson Airport, Payson, Arizona Date Tested 8-30-78

Location Taxiway & Parking Area

Station	Temperature Fahrenheit	Deflection 0.001"	Remarks
26+00 25' Right	101°	8	
26+00 50' Right		6	
26+00 75' Right		4	
26+00 100' Right		7	
26+00 125' Right		5	
26+00 150' Right		4	
26+00 175' Right		10	
26+00 200' Right		10	
26+00 225' Right		16	
26+00 250' Right		14	
26+00 275' Right		20	
26+00 300' Right		12	
26+00 325' Right		20	
26+00 350' Right		20	
26+00 375' Right		30	

BENKELMAN BEAM

Subject Payson Airport, Payson, Arizona Date Tested 8-30-78

Location Taxiway & Parking Areas

Station	Temperature Fahrenheit	Deflection 0.001"	Remarks
26+15 225' Right		14	
26+25 250' Right		20	
26+50 175' Right		6	
26+50 200' Right		16	
26+50 225' Right		10	
26+50 250' Right		20	
26+50 275' Right		10	
26+50 300' Right		20	
26+50 325' Right		14	
26+50 350' Right		20	

Appendix C

LIME-STABILIZED SOIL FOR USE AS BASE COURSE

(A suggested specification)

1.0 LIME-STABILIZED SOIL BASE COURSE

1.1 Description. This item shall consist of constructing one or more courses of a mixture of soil, lime, and water in accordance with this specification, and in conformity with the lines, grades, thicknesses, and typical cross sections shown on the plans or established by the engineer. The use of this item is restricted to pavements designed for aircraft weighing less than 12,500 lb.

2.0 MATERIALS

2.1 Hydrated Lime. Hydrated lime shall conform to the requirements of ASTM C-207, Type N.

2.2 Quick Lime. Quick lime shall conform to definitions of ASTM C-51.

2.3 Commercial Lime Slurry. Commercial lime slurry shall be a pumpable suspension of solids in water. The water or liquid portion of the slurry shall not contain dissolved material in sufficient quantity naturally injurious or objectionable for the purpose intended. The solids portion of the mixture, when considered on the basis of "solids content," shall consist principally of hydrated lime of a quality and fineness sufficient to meet the following requirements as to chemical composition and residue.

(a) Chemical composition. The "solids content" of the lime slurry shall consist of a minimum of 70%, by weight, of calcium and magnesium oxides.

(b) Residue. The percent by weight of residue retained in the "solids content" of lime slurry shall conform to the following requirements:

Residue retained on a No. 6 (3360-micron) sieve ....Max. 0.0%

Residue retained on a No. 10 (2000-micron) sieve ....Max. 1.0%

Residue retained on a No. 30 (590-micron) sieve ....Max. 2.5%

(c) Grade. Commercial lime slurry shall conform to one of the following two grades:

Grade 1. The "dry solids content" shall be at least 31% by weight, of the slurry.

Grade 2. The "dry solids content" shall be at least 35%, by weight, of the slurry.

2.4 Water. Water used for mixing or curing shall be reasonably clean and free of oil, salt, acid, alkali, sugar, vegetable, or other substances injurious to the finished product. Water shall be tested in accordance with and shall meet the suggested requirements of AASHO T 26. Water known to be of potable quality may be used without test.

2.5 Soil. The soil for this work shall consist of materials on the site or selected materials from other sources and shall be uniform in quality and gradation, and shall be approved by the engineer. The soil shall be free of roots, sod, weeds, and stones larger than 2 1/2 inches.

3.0 COMPOSITION

3.1 Lime. Lime shall be applied at the rate specified on the plans for the depth of subgrade treatment shown. The resulting mixture shall have an unconfined compressive strength of at least 80 psi based upon tests of samples sealed and cured at 120°F for 30 hours.

3.2 Tolerances. At final compaction, the lime and water content for the base course shall conform to the following tolerances:

Lime ....±0.5%
Water ....+2%, -0%

4.0 WEATHER LIMITATIONS

4.1 Weather Limitations. The lime-stabilized base course shall not be mixed while the atmospheric temperature is below 50°F. or when conditions indicate that temperature may fall below 50°F. within 28 days when it is foggy or rainy, or when soil or subgrade is frozen.

5.0 EQUIPMENT

5.1 Equipment. The equipment required shall include all equipment necessary to complete this item such as: grading and scarifying equipment, a spreader for the lime or lime slurry, mixing or pulverizing equipment, sheepsfoot and pneumatic or vibrating rollers, sprinkling equipment, trucks, and truck scales. All machinery, tools, and equipment shall be on the site and approved by the engineer prior to the beginning of construction operations and shall be maintained in a satisfactory working condition throughout the construction period.

6.0 CONSTRUCTION METHODS

6.1 General. It is the primary requirement of this specification to secure a completed base course containing a uniform lime mixture, free from loose or segregated areas, of uniform density and moisture content, well bound for its full depth, and with a smooth surface suitable for placing subsequent courses. It shall be the responsibility of the contractor to regulate the sequence of his work, to use the proper amount of lime, maintain the work, and rework the courses as necessary to meet the above requirements.

Prior to beginning any lime treatment the base course shall be constructed and brought to grade as specified in Item P-152 "Excavation and Embankment" and shall be shaped to conform to the typical sections, lines, and grades as shown on the plans or as established by the engineer. The material to be treated shall then be excavated to the secondary grade (proposed bottom of lime treatment) and removed or windrowed to expose the secondary grade. Any wet or unstable materials below the secondary grade shall be corrected, as directed by the engineer, by scarifying, adding lime, and compacting until it is of uniform stability. The excavated material shall then be spread to the desired cross section.

If the contractor elects to use a cutting and pulverizing machine that will remove the subgrade material accurately to the secondary grade and pulverize the material at the same time, he will not be required to expose the secondary grade nor windrow the material. However, the contractor shall be required to roll the subgrade, as directed by the engineer, and correct any soft areas that this rolling may reveal before using the pulverizing machine. This method will be permitted only where a machine is provided which will insure that the material is cut uniformly to the proper depth and which has cutters that will plane the secondary grade to a smooth surface over the entire width of the cut. The machine must give visible indication at all times that it is cutting to the proper depth.

6.2 Application. Lime shall be spread only on that area where the first mixing operations can be completed during the same working day. The application and mixing of lime with the soil shall be accomplished by the methods hereinafter described as "Dry Placing" or "Slurry Placing."

(a) Dry placing. The lime shall be spread uniformly over the top of the subgrade by an approved screw-type spreader box or other approved spreading equipment. The amount of lime spread shall be the amount required for mixing to the specified depth which will result in the percentage determined in the job mix formula.

The lime shall be distributed in such manner that scattering by wind will be minimal. Lime shall not be applied when wind conditions, in the opinion of the engineer, are detrimental to a proper application. A motor grader shall not be used to spread the lime. The material shall be sprinkled, as directed by the engineer, until the proper moisture content has been reached.

(b) Slurry placing. The lime shall be mixed with water in trucks with approved distributors and applied as a thin water suspension or slurry. Commercial lime slurry shall be applied with a lime percentage

not less than that applicable for the grade used. The distribution of lime shall be attained by successive passes over a measured section of subgrade until the proper amount of lime has been spread. The amount of lime spread shall be the amount required for mixing to the specified depth which will result in the percentage determined in the job mix formula. The distributor truck shall continually agitate the slurry to keep the mixture uniform.

6.3 Mixing. The mixing procedure shall be the same for "Dry Placing" or "Slurry Placing" as hereinafter described:

(a) First mixing. The full depth of the treated base course shall be mixed with an approved mixing machine. Lime shall not be left exposed for more than six hours. The mixing machine shall make two coverages. Water shall be added to the subgrade during mixing to provide a moisture content above the optimum moisture content of the material and to insure chemical action of the lime and soil. After mixture, the base course shall be lightly rolled to seal the surface and help prevent evaporation of moisture. The water content of the base course mixture shall be maintained at a moisture content above the optimum moisture content for a minimum of 48 hours or until the material becomes friable. During the curing period, the material shall be sprinkled as directed. During the interval of time between application and mixing, lime that has been exposed to the open air for 6 hours or more, or to excessive loss due to washing or blowing will not be accepted for payment.

(b) Final mixing. After the required curing time, the material shall be uniformly mixed by approved methods. If the mixture contains clods, they shall be reduced in size by blading, discing, harrowing, scarifying, or the use of other approved pulverization methods so that the remainder of the clods shall meet the following requirements when tested dry by laboratory sieves:

Minimum of clods passing 1 1/2-inch sieve 100%
Minimum of clods passing No. 4 sieve 60%

6.4 Compaction. Compaction of the mixture shall begin immediately after final mixing. The material shall be aerated or sprinkled as necessary to provide optimum moisture. Compaction shall begin at the bottom and shall continue until the entire depth of mixture is uniformly compacted. The entire thickness of the treated base course shall be compacted to a density of at least 95% of maximum density at optimum moisture, as determined by the compaction control tests in Item T-611.

The material shall be sprinkled and rolled as directed by the engineer. All irregularities, depressions, or weak spots which develop shall be corrected immediately by scarifying the areas affected, adding or removing material as required, and reshaping and recompacting by sprinkling and rolling. The surface of the course shall be maintained in a smooth condition, free from undulations and ruts, until other work is placed thereon or the work is accepted.

In addition to the requirements specified for density, the full depth of the material shown on the plans shall be compacted to the extent necessary to remain firm and stable under construction equipment.

After each section is completed, tests will be made by the engineer. If the material fails to meet the density requirements, it shall be reworked to meet these requirements. Throughout this entire operation, the shape of the course shall be maintained by blading, and the surface upon completion shall be smooth and shall conform with the typical section shown on the plans and to the established lines and grades. Should the material, due to any reason or cause, lose the required stability, density, and finish before the next course is placed or the work is accepted, it shall be recompacted and refinished at the sole expense of the contractor.

6.5 Lime content. The lime content of the uncured lime-treated base course shall be determined by ASTM D-3155 procedures at intervals so that each test shall represent no more than 300 square yards of material. When lime content varys from the design content by more than ±1/2 %, the contractor shall correct such areas in a manner satisfactory to the engineer.

6.6 Finishing and Curing. After the final layer or course of lime-treated base course has been compacted, it shall be brought to the required lines and grades in accordance with the typical sections. The completed section shall then be finished by rolling, as directed, with a pneumatic or other suitable roller sufficiently light to prevent hair cracking. The finished surface shall not vary more than 3/8-inch when tested with a 16-foot straightedge applied parallel with and at right angles to the pavement centerline. Any variations in excess of this tolerance shall be corrected by the contractor, at his own expense, in a manner satisfactory to the engineer.

The completed section shall be moist-cured for a minimum of 7 days before further courses are added or any traffic is permitted, unless otherwise directed by the engineer. Subsequent courses shall be applied within 14 days after the lime-treated base course is cured.

6.7 Thickness. The thickness of the lime-treated base course shall be determined by depth tests or cores taken at intervals so that each test shall represent no more than 300 square yards. When the base deficiency is more than 1/2-inch, the contractor shall correct such areas in a manner satisfactory to the engineer. The contractor shall replace, at his expense, the base material where borings are taken for test purposes.

6.8 Maintenance. The contractor shall maintain, at his own expense, the entire lime-treated base course in good condition from the start of work until all the work has been completed, cured, and accepted by the engineer.

7.0 METHOD OF MEASUREMENT

7.1 The yardage of lime-treated base course to be paid for shall be the number of square yards completed and accepted.

7.2 The amount of lime to be paid for shall be the number of pounds of quicklime, hydrated lime (or the calculated dry-lime content of the lime slurry) used as authorized.

8.0 BASIS OF PAYMENT

8.1 Payment shall be made at the contract unit price per square yard for the lime-treated base course of the thickness specified. The price shall be full compensation for furnishing all material, except the lime, and for all preparation, delivering, placing and mixing these materials, and all labor, equipment, tools and incidentals necessary to complete this item.

8.2 Payment shall be made at the contract unit price per pound of lime. This price shall be full compensation for furnishing this material; for all delivery, placing and incorporation of this material; and for all labor, equipment, tools, and incidentals necessary to complete this item.

Payment will be made under:

8.1 Lime-treated base course ..... per square yard
8.2 Lime ..... per ton

9.0 TESTING AND MATERIAL REQUIREMENTS

Test and short title	Material and short title
AASHO T26--Water	ASTM C 207--Lime
FAA T-611--Density	ASTM C-51--Lime
	ASTM D 3155--Lime Content


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